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CAVE HUNTING IN YUCATAN.

BY HENRY C. MERCER.

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INTRODUCTION.

CAVE HUNTING EXPLAINED.

Two years ago the Corwith expedition of the University of Pennsylvania (under the kind auspices of Dr. S. Weir Mitchell, and named after its generous donor, Mr. John W. Corwith, of Chicago) set out at rather short notice to open, it seemed, a new field of archæological research in Yucatan. We were going to hunt in caves for evidence of man's antiquity. We asked how long man had inhabited Yucatan, and under what circumstances he had first arrived there. Not that the question had not been asked before by Stephens, Waldeck, Charnay, and other explorers, who had speculated upon the age of the ruins of Central America; but we thought that we were possessed of a way of getting at the question that was quicker, surer, and more conclusive than theirs. We were going to test the antiquity of the man that built the wonderful ruins, and gauge his original state of culture, not by the ruins themselves, but by the traces of his presence left by him in caves; and we were the more confident of success from the fact that the caves, abundant as they were in the region, had never before been

searched. We were the first upon the field — the first to attempt to translate their hidden contents.

But why search caves? Why go under ground? Why leave the daylight and all the beauty and wonder of the ruins to delve in damp, dark holes, where at most we proposed to find a few broken pieces of pottery, a few fragments of bone or chips of flint upon which the visitor at a museum might scarcely bestow a glance.

On the answer to this question hangs the whole justification of our attempt, and that answer is, that science has shown that if you want to get to the bottom, to the beginning of the human story, you must hunt in a cave. Science has shown that most if not all primitive peoples, when confronted by caves which were accessible, light and dry, at some time or other entered them. When they did it has appeared that they built fires on their floors and scattered the bones of cooked animals near by, until caked deposits of rubbish were trodden down upon the foothold, and until these, when interbedded with bands of loam or leaves or stalagmite, proving intervals of time when the cave was vacant, presented us with a series of epoch-denoting layers resting upon the cave floor, one upon another, the oldest on the bottom and the latest on the top. Science has thus shown that before artificial houses were built, man entered these natural houses prepared for him by an ancient geological process before his coming, and outlasting his day, and that there, where the rock walls and the limit of light and darkness compelled all cave visitors to inhabit the same area, the whole problem of sequence, of who came first and who came last, layer upon layer was buried at one spot. For these reasons a great number of caves were excavated in England, Belgium, France, and Germany, and a large amount of evidence collected, which over and over again repeated the same story.

Where does the word prehistoric gain its significance? What signifies this classification in ages and epochs of man's culture in the last fifty years? What justifies us in saying that during a series of millenniums before Herodotus and Pliny, before the dawn of history, man had bronze before he had iron; that older than bronze was polished stone; and that older than polished stone was chipped stone; that with bronze and polished stone man had domestic animals, but with chipped stone, none; that during the bronze and polished stone time animals were recent, while during the older chipped stone epoch they were of species now extinct? Let it be said again, in answer to

these questions, that nothing has so well established us in this new knowledge, now not over fifty years old, as the investigation of layers in caves.

No doubt that these cave layers are often missing. No doubt that they are often disturbed, and that there is often much confusion in the record; but as far as Europe is concerned, that man was present and left his footprints in available caves, there can be no doubt. From the man of history to the man with bronze, from the man with bronze to the man with stone, from the recent man to the fossil man, as far as Europe is concerned, all have left their traces in caverns and rock shelters. Now, if science has shown this in Europe, what shall it show for America? When we come to look shall we find that the same rule of superposed epoch-denoting culture layers holds good here? Can we dig down into the subterranean floors and find fossil man here as we found him there? These are questions which I began to ask four years ago, and am still asking, and all that I have yet to present is a narrative of how, in one way or another, I have found the evidence in American caves scanty and shallow, and of how up to date I have failed to find fossil man.

What if we continue to fail to find him? What if we find that he does not exist anywhere in the caves of America? What if we go down the Ohio and Kanawha and Delaware and Susquehanna, as I have done for the last three years, preferring the great waterways and passes where savages would have crossed the Appalachian barrier from east to west, or west to east, and find that this earlier fossil savage, who should have been a contemporary of the extinct animals, is always missing? What if as against all the culture layers of Europe we here find only one — always find the Indian and nothing but the Indian, represented by a characteristic rubbish band composed of familiar arrowheads, potsherds, and bone needles on the floors of all these caves; and what if beneath this in the ancient red or yellow cave earth we dig again and again to the mother rock, to find sometimes the bones of bats or rabbits, or the remains of snails, sometimes the vertebræ of the great sloth, the teeth of the tapir, or the jaws of the mylodon or peccary, but never a trace of humanity?

Such is the kind of evidence thus far gleaned by us from the American caves; but before trying to draw a conclusion from it, it remains to be asked, have we gone far enough? Have we searched enough caves to warrant us banishing fossil man from the eastern

region or setting a geological limit to human existence in the New World? Have we investigated regions where we might expect to find man older than elsewhere? And our expedition to Yucatan was a reply to this by pushing the research into a district where it seemed that man should have been old if he was old anywhere on the continent.

Yucatan Promises to Solve the American Problem.

Judged by the test of written language, the old inhabitants of Yucatan might reasonably be placed at the head of all the people found by Columbus in the New World. The Peruvians had *quipus*, tally-knots on thongs or strings, by which something previously learned by heart was suggested to the expert reader. The Mexicans had picture writings more or less symbolic. But the Mayas whom the Spaniards found in Yucatan used hieroglyphics where a symbol comes to stand for the object, and the mind prepares itself to invent an alphabet. The Peruvians were master masons in the massiveness of long and high walls built of immense hewn blocks. The Mexicans were lofty mound builders, and the people of the Ohio valley constructors of such great and elaborate earthworks as you see at Marietta, or at that poetically beautiful fair ground at Newark; but the carved palaces of the Mayas, overloaded with mysterious symbolism whose ruins still astonish the traveler in the forest of Yucatan, exceeded everything. We had a notion of a sort of civilization older than that of Mexico buried away in the wilderness, of something that even the Indians had themselves forgotten when the Spaniards came, of something more ancient, more elaborate, more marvelous in Yucatan than anywhere else from Behring Straits to Patagonia; and when we learned from Professor Heilprin that in the very midst of all these awe-inspiring ruins described by Stephens and Waldeck, by Charnay and Maler, there were abundant dry and spacious caverns which none of these travelers had explored, it seemed as if we had the question of man's antiquity in America presented to us in a nutshell. There where man had reached the highest point of semi-civilization or barbarism in the new hemisphere, it seemed as if all the doubts as to his antiquity could once and for all be set at rest. If he was old anywhere he was old there. If the American problem could be settled anywhere it could be settled in Yucatan.

The American Problem.

But what is the American problem, and why settle it? Has it not been settled before? Do we not know how old the Indians are? Have we not the Calaveras skull and pestles and mortars excavated from the bottom of gold mines? Have we not the Trenton "turtle backs" chipped by human hands and gathered from a bank of gravel on the Delaware River, which, by the last of the geological time estimates, should be about 32,000 years old? Dr. Koch's spear-heads, with mastodon remains, chipped blades from the beds of fossil lakes, and a dozen other evidences of man's great antiquity — do they not prove that long before the Indian as we know him, we may look back into the geological past and behold humanity here as in Europe, a contemporary of the mammoth and the mastodon, the saber-toothed tiger, and the fossil horse? Let it be answered that in spite of all thus far presented on the subject, we are still in doubt if not darkness. Let him who supposes that all these things described and recapitulated in the introductions of recent text-books and histories are proved and settled, try to investigate them for himself. When he does he finds that what he had regarded as well-fixed facts fade away like stories of ghosts and haunted houses at near approach. He learns that while in Europe it is an easy matter for you or me to step upon a railway train and go to any one of a score of sites where human remains can be found at short notice with the bones of extinct animals, here, on the other hand, we may assert that no explorer will venture to lead us to-morrow or next week by a journey long or short (which some of us would willingly take) to any point whatsoever east of the Mississippi, where he can guarantee us a sight of fossil man or of one of his implements in place. As far as America is concerned, *homo fossilis* is desperately hard to find.

This, then, is the problem of man's antiquity in America; we do not know how long man was here. The red man was found here, but we have not yet accounted for him. Let alone the question of the Indian's predecessor if he had one, we do not know where the Indian came from. We cannot say whether his development of language, of architecture, and varying customs, whether his dissemination of maize, his apparent domestication of the dog and the llama, whether all this is an affair, geologically speaking, of modern times, or of a longer epoch; of the time represented by the forest loam under our feet that

grows western wheat without manure, of the present existing plants and animals, and of the outlines of the country as we now know them, or of a time denoted by a race of animals that is extinct and measured, according to Spencer's late work at Niagara Falls, by a lapse of 32,000 years. This is the question at the bottom of American archæology. This is the question that we went to Yucatan to settle, and to settle by means of hunting in caves.

Marvelous as were the ruins, interesting as were the Indians themselves, the descendants of the builders of the ruins, we turned away from them to dig under ground, for there we ventured to believe that the truth might be demonstrated for the first time. Somewhere, very deep in the cave earth under the crusts of refuse left by the builders of Uxmal and Labna, we must find the trace of fossil man if he had existed in the region. Well might the sites of the known ruins excavated to their full depth fail to reveal his presence, but here, if his footsteps had ever trod the peninsula, he could not escape us.

Such, then, was the promised glimpse of a new knowledge hidden in a dark chamber of which we had the key, that thrilled us with excitement as we set sail for Yucatan. And this is the only consideration, perhaps, that warrants me in coming here to describe our journey as a thing at all memorable, or different from the ordinary experience of travelers who visit the mysterious and little-known land of which I shall speak.

The People of Yucatan.

So hurried had been our packing up and departure that we had hardly had time to imagine the kind of people and country that we were to see. We knew that there was a semi-tropical forest, and we imagined orchids and birds of gay plumage. We knew of the marvelous ruins hidden in thickets, where, as in the fairy tale of the "Sleeping Beauty," you cut passages with axes to see deserted palaces that lie concealed only a few yards away. We had been warned against snakes; and to wade through the jungle, as we imagined it, we had taken leather leggins made nearly waist high, and I was prepared to invent better ones and cooler, of fine wire netting, that I thought seriously of having patented. We had heard stories of treachery, and that it would be unsafe to wander away alone with Indians. Hence pistols

FIG. 2. CAVE OF LOLTUN. (*Rock of Flowers.*)

Probably the most beautiful cavern in Yucatan. Situated in a forest solitude near the hacienda of Tabi. Its several spacious rotundas connected by dark passages are lit from above by skylights fringed with forest. Below colored stalactites a graceful underground vegetation charms the eye, and there, water, ever precious in the parched land, drips from shadowy ceilings into ancient dishes of stone. In the charcoal-blackened floors the sought-for proof of human presence was found, which, it is believed, has thrown for the first time the light of reasonable surety upon the antiquity and culture of the ancient peoples of Yucatan; setting limits to future speculation, and preparing the way for a just interpretation of the grotesque ruins, the strange mural decorations, and the hieroglyphs, still unread, that Stephens and Waldeck described to astonished hearers half a century ago. The view is taken in the second or largest rotunda. The Indians are sitting on the edge of trench No. 1, beyond which the dark passage on the right leads to the entrance.

were a necessity. In the rock pools beset with bacteria we were warned not to bathe, much less dared we drink the water, full of fever germs as it was, without previously boiling it. But the first sight of Yucatan suggested another danger against which we had taken precautions in the form of a supply of quinine — namely, fever.

The water rippled by a gentle wind looked green where we lay at anchor one morning, after a seven days' sail from New York, and the shore three miles away seemed yellow and very low. At one spot there were outlines of buildings, and some palm trees raised their graceful fronds through a stratum of vapor. Mr. Armour, whose yacht lay near, and who kindly helped us through the custom house, came aboard and warned us against the feverish place, Progresso by name, advising us to lose no time in leaving it for Merida, forty miles inland. His expedition had been confronted with danger and difficulty. Uxmal was certain malaria; Tuloom was held by hostile Indians who had just murdered the Spanish governor; members of his party had been driven to desperation by wood lice, and their botanist was ill. The prospect looked discouraging; but once ashore, the responsibility of our long list of bags and boxes, the novel and reassuring look of the place and people, drove doubts to the dogs.

And it was these Maya people who first and last attracted us, while, indeed, a great deal depended on them. If they were to be dirty, surly, cheating, avaricious, or treacherous, if they were to refuse us permission to dig into the remains of their ancestors, we were at their mercy. But in all respects we were most agreeably disappointed with them; and in the first place, I think I may say that they gave the impression of being the cleanest people I ever saw, my own countrymen not excepted.

The white muslin that dazzled the eye in the sun seemed always white; faces, often smooth-shaven in the Spanish fashion, were clean, and hair well brushed and cut. Where the water came from for the ablutions was a mystery, in a land where it was so scarce. But in this respect our cook, Pastor Leal, put us to shame. On sweltering days, after long walks through the woods when we looked and felt like repulsive vagabonds, he in his white muslin jacket was apt to present the appearance of a very elaborate bartender at some very luxurious hostelry, with a rose in his buttonhole.

No stabbing in the back in Yucatan. No muffled figures lurking around corners with *machetes* as in other parts of Mexico and Cuba.

An overseer told me, strange to relate, that when the Indians fought, they fought with their fists. So we put away our pistols as useless things, and when after weeks of experience with open doors, and with our rooms scattered with valuables that were never found missing but once, we were ready to admit the truth of Professor Heilprin's expression, that the only thief he had met in Yucatan had come from Philadelphia.

But how was this to be explained? Who were these people? Why were they so much more attractive and gentle than any one else? Why different from the Cubans or Mexicans? Were they not Spanish with a little Indian blood in their veins? The answer to these questions seemed to lie in the important fact that they were rather Indians with a little Spanish blood in their veins. A very few of the important families were pure Castilians. All the rest were mixed, and the darker they were, it seemed the kindlier, the cleaner, and the more good-natured.

What an important fact to realize, that the Maya people, who built the great ruins of Central America, have not been stamped out of existence like our Eastern Indians. There they are still to be studied, and I will add, liked by any one who goes to Yucatan. Comprising four-fifths of the present population, they still speak one of the most interesting of the languages of ancient America, and the only one that ever was written. Like many a conquered race, they seem to be absorbing their conquerers.

Their kindness smoothed our way everywhere. The Bishop of Yucatan, to whom we had a letter of introduction from Dr. Brinton, presented us to the large landed proprietor, Señor Escalante, and he to Señor Duarte and to the governor. It so happened that a line of great plantations (*haciendas*) lay along the hills in our way, and we were to travel to and from them. Instead of camping in the forest, we were to sleep under their shelter, and when we found what the forest was on the one hand, and the *haciendas* on the other, we thanked our stars.

Not soon shall I forget our first impression of a *hacienda* at Chalcetok. A tram car awaited us at a wild little spot called San Bernardo, and piling our baggage upon it, a single mule whisked us at a run through the evening air. Across broad fields of the hemp cactus called Hennequin (*Agave sisalensis*) we rattled. Then came a smoke stack in the distance, then a village of thatched huts built of mud and

FIG. 3. MEZTIZA GIRL.

wattle, where at each door you saw half-naked children, figures in white dress, against the characteristic outline of the swinging hammock, and at last the court surrounded by graceful buildings and round arches supported on pillars. By these picturesque galleries under the palm trees, white-robed figures came and went. From a chapel near by a bell rang, and we heard the sing-song of children's voices repeating a prayer. Then the overseer received us, and going in, our party of five, Mr. Corwith and myself, with our secretary, assistant, and two cooks, took possession of three large bare rooms, one of which was a kitchen. While the hammocks were being hung on hammock pegs I walked out on the terrace and looked about. Somehow the scene reminded me of Egypt. The walls, the palm trees, the blue scarves in the twilight were oriental, but the forest seemed strange. I saw it beyond upon the hills, and it stretched away into the horizon, surrounding us with mystery, and shutting off the spot from the nineteenth century and the world. Behind the hemp mill there were gardens, beautiful orange groves hanging heavy with fruit, and birds that sang all day. There were large water tanks and channels of masonry where artificial streams flowed as you see them in gardens in the Levant. After the coming of night and by the rise of the moon, we desired but little to go to bed and lose sight of a reality stranger than fiction. Rather might we have sat up all night imagining ourselves in a land of Lotus or some garden of the Arabian Nights.

Tabi was another *hacienda*, and Yokat another even more beautiful, each of which we left with regret, and each of which vied with the other in hospitality. Sometimes villages lay near us, whither, if not too tired, we might walk of an evening to some public entertainment or a *mestiza* dance. In Merida we had been to an opera and seen the "Huguenots," where all the ladies, seated in boxes, considered it their duty to put on their best French dresses and sit through the performance more or less bored to death. What a contrast was the nocturnal scene that confronted us in the open air at Opichen!

Round about us among flickering torches stood little thatched booths where they cooked cocoa in open fires, or made you strange salads and highly seasoned dishes, and where you smoked highly flavored cigars to the echoes of music half Spanish, half Maya, played on fiddles and flageolets. The strains came from a large shed open on the sides and full of dancers. But I must say the dance was a disappointment; that it lacked the action, the spice that I expected. When

one of the Meztiza girls so celebrated for attractiveness danced, she danced alone, and to our minds spoiled her appearance by putting on a man's hat. Several times with stiff solemnity her partner circled about her, and then the two separated, she going one way and he the other. I had heard no loud talking in Yucatan, and here, where demonstrative conversation seemed out of fashion, met no exception to the rule. No audience at a temperance lecture could have taken matters more seriously than did these people during the solemn intermissions. But at these times outside the shed the hospitality which we had met with everywhere was clearly shown. We appeared to be guests of the village, and could pay for nothing. Indians that we had never heard of before forced expensive cigars upon us again and again. It was no use to cry "Hold, enough." I went away with my pockets full of costly "puros" done up in lead foil.

In our many wanderings into the woods with the Maya Indians, in our long diggings with them in subterranean depths where we were not rarely at their mercy, we found them faithful, gentle, and kind. Incapable of handling a shovel correctly, they would pile the blades full of earth with their hands, strike absurd blows, and work with the wrong end of the pickaxe. Yet these were laughing matters. They were children always; you could no more scold them than you could beat a delightful puppy who nibbles the corner of a favorite book.

But a dreadful accident that overtook our party at a cave brought us nearer to them, perhaps, than anything else, and I doubt if any civilized people could have behaved with more dignity and refinement when confronted by sudden and tragic death. We were in a deep, well-like rotunda, where for hours we had been at work. Seated on a mossy rock I was writing my notes while the boughs of several trees that grew from the floor through the skylight rustled overhead. In their high tops two barefooted Indians who had followed us were climbing from bough to bough like monkeys, as with their knives they cut green branches for their cattle at home. Throwing these upon the neighboring ledge at the chasm's brink, one of the men stepped across, seized a pile of the twigs and began to tie them into a bundle. He had pulled them together, and kneeling with his head in the leaves was straining with outstretched arms to bring the mass within reach of a string, when, pushing too hard and too far, the brink betrayed him. I heard a great rattle, saw the fluttering boughs, and then the figure in mid-air, dashed in an instant head foremost upon the cruel rocks at

my feet. In a few seconds he had ceased breathing, and his comrades, raising him gently, felt his last heart-beats. Till all was over they looked solemnly on. Then one went away to appear in an hour with a band of friends, who, cutting boughs with their knives and tying them into a litter with a blanket stretched across it, laid upon it the body which we had meanwhile lifted from the cavern with a rope. Last of all one of them descended the chasm, and carving a cross upon the tree, scattered earth upon the fatal stains. This done we marched away in solemn procession to reach home at nightfall, when piteous wailings echoed through the village of Yokat, and we learned that the night which followed had witnessed a wake, a *baloria* differing a little from the weird ceremony so familiar in Ireland.

I believe it would be so easy to become fascinated with the ruins of Yucatan and an investigation of its past glories, as to look with too great unfriendliness upon the influence brought to bear by Europeans upon the Indians, and for that reason I cannot agree with Stephens, who continually refers to the present Mayas as a lost, degraded, and ruined race. Our observations, I admit, were superficial, and we made no careful analysis of the people. But when all is summed up, I imagine that, living as they now live, whether rooted by a sort of vassalage upon the plantations, or revolted and run wild in forests, they are better off in the scale of human development than when, at the head of aboriginal American culture, they were yet ignorant of the more useful metals and domestic animals, and stained with the cruelty of horrible human sacrifices. I would rather believe that they have a future, and are working it out by one of the most potent of all means, namely, blood alliance with the conquering race.

The Forest of Yucatan.

So much for the people; but what of the conditions of travel in Yucatan? The roads, they were abominable. You jolted over bowlders, rock seams, and ledges, at a run in carts with enormously heavy, tired wheels, squirming in swinging boxes on mattresses of vegetable pollen, and tossed like dice in a dice-box. The food? That we carried with us and cooked ourselves. Black beans; rarely meat when a bull was killed; cocoa, red wine from France, and ham from the United States; rice and potatoes, sometimes delicious fruits that we had never tasted before, and oranges. What would we have done without them

to quench our thirst after long tramps, when we rolled bags full of them upon the floors of caves where there was no water? But most of the danger and much of the difficulty of exploration in Yucatan are embodied in one fact, and that fact is the existence of the forest. I had expected to see a luxuriant Amazonian tangle, to stumble over the roots of enormous trees festooned with orchids, to feel the damp touch of succulent leaves where serpents lurked and insects swarmed, to wonder at the color of butterflies and parrots. Instead, I saw a stunted, leafless thicket thickly tangled with thorns, not more striking in appearance than some dry swamp overgrown with alder and blackberry bushes in the United States in December. There were no large trees, no patches of grass, no colors; there was no noise of insects and no superabundance of birds. Under foot lay withered leaves, dry, loose stones, and ledges of yellow rock.

In this wilderness the traveler loses his way. Fever attacks him. The explorer, devoured with wood-lice, fails of heart. And where are you going to dig, among the stones, dead leaves and briers? In certain places where the thin, red soil has collected lie *haciendas* with fields of hemp, sugar cane, or maize. But elsewhere from Chiapas to Belize, from the Gulf on the north to the Cordil-dil-lieras on the southwest, this tangled, thirsty thicket covers everything. Revolted Indians hiding away in it, and using it as a bulwark against their enemies, hold their own in its depths. I do not believe the rumors of temples and cities still flourishing in it unknown to white men, but I am sure that Maler has found many structures buried in its recesses that escaped Stephens, Waldeck, and Charnay, and that no one ever heard of before, though those known to us, like Uxmal, Labna, and Chichenitza, are wonderful enough.

Not yet, owing to the difficulty of digging in the stones and briers, or of cutting down the thicket, and building scaffolds so as to even see or photograph them, have they been adequately excavated or studied. And there they stand, rapidly vanishing, it must be said, because of their imperfect construction. And because their walls rest on no true arches, because the joints are not bound nor the stones squared, and because the facing is not linked to the heart, they crumble to pieces more rapidly than the ancient buildings of Egypt and Assyria, Rome and Greece.

Some are easy to reach. You might sail from New York and see Uxmal in ten days, but I am half glad that stories of fever and snakes,

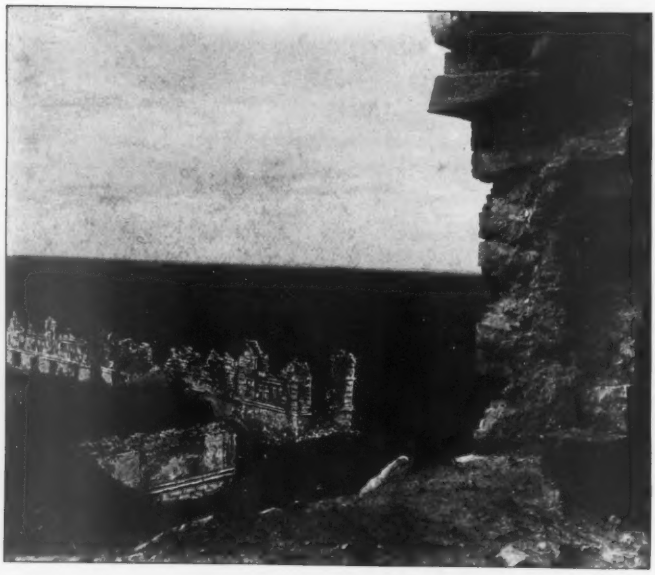


FIG. 4. VIEW FROM THE DWARF'S HOUSE AT UXMAL.

heat and thirst, have frightened away the horde of tourists who, rushing in, would rob the region of its unconscious charm. So let the ruins remain in solitude. Let them disappear in silence surrounded by all the mystery of the forest.

At Uxmal these marvelous structures are set on high mounds and platforms that look like natural hills as you catch glimpses of them from the distant sierra. The so-called House of the Dwarf stands upon the highest mound of all, and you climb to it on a stone face by narrow and steep steps, where a fall would be no less sure death than a slip on the sides of the great Pyramid at Gizeh. The wind blew fiercely when we stood there for the first time, and fortunately for us, heavy clouds drifted across the sky, darkening the strange walls below us, that rose out of the thicket. The wilderness stretched away to the hills. As we had seen it often before from the sierra, it had assumed again that day its tint of deceitful blue. It seemed as if there were cool places where rivers flowed, and where the cloud shadows fell upon it, pleasant lawns and high trees. But these mirage-like allurements were the false wiles of the ever-present forest, here as parched, shadeless, and thirsty as ever.

In the tangle of thorns below, all sign of communication between building and building, all traces of smaller dwellings, of aqueducts or roads, seemed to be lost. But who had yet had the strength or courage to search for these things in this most feverish of places, where at one time even the cattle died; where I was told that Indians did not survive two generations? Hard enough was it to penetrate the curtain of briers and mantle of rubbish about the sides and walls of the great buildings, as Charnay and LePlongeon had done, so as even to photograph or study them. The House of Turtles, the Casa-del-Gubernador, the Nunnery; what significance had these names invented by the Spaniard, as we walked through a false arch into an immense courtyard, and saw walls on every side covered with a symbolism in stone that antedated the coming of the European? Monstrous masks, projections like the trunks of elephants, grotesque tongues, great eyes, rows of teeth, rising suns, phallic signs, and above all the great rattlesnake with plumed human head-dress confronted us with a meaning that was lost. It came upon the mind in a sense of something malevolent; something symbolic of horrible and bloody themes of sacrifice; of torture and awful ceremony in the native manuscripts. It seemed to rise from the forest and haunt the memory of our journey in

the wilds. Were we in the nineteenth century? Were we looking at things that had existed, or were we wandering in a land of dreams? In these strange impressions, never known before, we felt the fascination of ancient America so potent to encompass the searcher in the *tierra caliente* and lead him astray. So often had it betrayed him with strange fancies, that counting up the names of well-known explorers who have become disturbed or distressed in this study, which I pray you to excuse me from doing here, the French have invented a phrase of sinister meaning when they say: *Toutes les Americanistes devant fous.* All the students of ancient America go mad.

Caves.

But what of the caves which had occupied our thoughts continuously from the first? Did we succeed in exploring them, or the chief group of them that lay scattered among and between the ruined cities? Were they what we expected, and did they contain the evidence we sought? In answer to which questions let me say that our first look at the caves brought disappointment. Instead of being what I had expected to find them, they were unlike any caves I had ever seen before. Caves that contain the remains of men or animals in the United States or Europe generally open into the sides of cliffs or escarpments of rock. But these yawned down into the ground like wells, sloping inward like the sides of an ink-bottle. The fact was, there were no cliffs in Yucatan. No rivers had cut across beds of rock, thus laying bare caves in cross section. But erosion had proceeded directly downward till holes opened in the cave ceiling. Sometimes piles of stones had fallen into these skylights, almost reaching their overhanging edge. Often trees grew up to their brink. But you generally had to climb down on rude sapling ladders made by Indians, on trees or by ropes, and so difficult was it to get into many of these caverns, that they would have been ruled out of an explorer's consideration in other countries. Savage peoples preferring more accessible shelters would have avoided them, and so doubtful was it that many of them would contain all or any considerable part of the evidence we sought, that it seemed as though our expedition had already failed; as if, as far as cave hunting was concerned, we had come to Yucatan in vain. And for a time the prospect was discouraging in the extreme, until an overlooked consideration restored the caves to all

their importance. It was the consideration embodied in the word *agua*, water, one of the first and last words a traveler hears in Yucatan. Broadly speaking, the peninsula is waterless. A few exceptions confront us in the muddy, stagnant pools called *aguadas*, and a few stony channels on the northeast coast only active in the rainy season. But with these allowed for, there are no streams, springs, or lakes in the region. To get water you must go under ground for it. You must bore wells, or find it in caves where it drops from the roof. The ancient Mayas lived on rain water collected in the rainy seasons, and stored in cemented cisterns which now form one of the most important features of the ruins. But what did they do before the cisterns were built, before they had established themselves in the region and constructed the cities? The important answer to this question is, that the caves supply water, and that since the early immigrants could not bore wells in regions where there were no *aguadas*, they must needs have ransacked the caves for water or perished. And the evidence soon showed that from the time of their first coming they had entered the caves by ladders when necessary, and halted for a while near the refreshing pools or dripping stalactites.

So after all, the whole story of man's life in Yucatan was in our hands and lay buried in the caves. The lowest film of trodden earth, of charcoal, ashes, and pottery, marked the advent of the first comer, the uppermost that of the last, and when once we realized this, our work flourished. But the trouble of it was to get the right cave — a cave where the floor rubbish had not become mixed by sliding, where great blocks had not fallen from the ceiling to obstruct work, where we could dig to the living rock at the bottom without blasting or impossible expense; and at last we found it.

At a wild place in the hills called Oxkintok in the midst of a group of little known ruins, not half a mile from a stone mound that contained a complex series of passages described as a labyrinth, within walking distance of our headquarters at Señor Escalante's *hacienda* of Chalcetok, Mr. Corwith chanced upon a cave, which when we came to examine it promised to answer all our expectations.

Like all the other caves it was entered through an orifice or sky window. But the fallen rocks had so choked the entrance that ingress was easy. And one of the chief desiderata for the exploration of all caves was fulfilled when we found that even then in the midst of the dry season it dripped water, and that ancient stone dishes hollowed

from blocks of limestone lay about the floor or stood full of water under the stalactites. More than this, at the base of the skylight which lit the chamber at its farther end, lay a heap of stones which proved to consist largely of dressed blocks, chips, and partly worked water dishes left there by the ancient builders of the ruins, who were thus shown at the first glance to have come to the cave not only to get water, but to get stone. A few small crannies leading away from the spacious room had been walled up by the Indians as blinds for shooting doves. But it was the only room, and its smooth earthen floor presented the only place to dig. As sure as it was that the people of the surrounding ruins had visited this place to get water, so sure was it that proof of their presence in the form of layers of ashes, charcoal, and potsherds, of chips of stone or implements of bone, together with the remains of contemporary animals, lay under foot. No rocks obstructed us, and there was no chance for land sliding or disturbance. Directly in the middle of the chamber in the dim light of the roof window, we had found the place to settle the question of man's antiquity in Yucatan.

It was not light enough where we stood to blow out the candles by whose aid we had come stumbling onward for some distance through the darkness and over loose rocks. The Indians took off their sandals and set down the shovels and pickaxes, and the large round baskets supported by straps across their foreheads. We spread their contents — specimen bags, tape measures, monocular level, India-ink and pens — upon the ground, and then marked with trowels a rectangle to include the area of our trench, about 20 feet long by 4 broad across the middle of the cave floor.

No common curiosity, no desire to unearth beautiful vases, figureines of jade, or ornaments of obsidian, inspired us as the Indians began to dig. All these things lay above ground and around us in the mounds and cisterns, and in the rubbish near the ruins. We were hunting for a few broken potsherds and bones. But they were to tell us more than all the rest. They would answer the unanswered question, how long had man lived in Yucatan? — a question which here in the heart of prehistoric America we proposed to test for the first time, by searching for the earliest footprints of humanity in the earth beneath our feet.

We held the candles downward as the Indians turned up the lumps of earth with the pickaxes, and saw the ground caked thick with pot-

sherds and the bones of the deer. When we had dug a great hole 2 feet deep, we had passed a surface layer of human rubbish which we studied well, to find under it a band of comparatively undisturbed earth. When we had gone 5 feet another subdivision of the rubbish layer was plainly visible, some 15 inches thick, lying still deeper. The discolored earth was full of broken potsherds of various colors and makes, and intermixed with the bones of still existing animals, while in it and below the surface we found no trace of the Spaniard. Very certainly we were working among the leavings of the builders of the ruins, but we soon left the rubbish behind us and dug downward into the unknown. The earth was red and comparatively soft. The pit grew to the depth of 7, 10, and 12 feet. Days passed as we toiled on. At each new digging we clambered down to go over the bottom inch by inch with trowels and candles. We built props against the side so as to scrutinize them in the gloom for traces of layers. The small snail shells and bat bones continued, but the charcoal and ashes had stopped, and with them all traces of man. What would come next?

How shall I describe the intervals when I walked about the cavern as the work went on; while I looked at the colors of the tinted stalactites overhead; while the weird rustling of the banana trees that rose from the cave floor through the skylight, and beat the crusts with their boughs, filled the cave with echoes, or slanting sun gleams fell upon our heap of oranges till they glowed in the twilight like tongues of flame. The fact that we were upon the track of a new knowledge inspired us. If man were to intervene between us and the living rock, he was the predecessor by a long interval of the ruin builder; perhaps a stone chipper ignorant of the art of polishing stone, perhaps an undeveloped or ape-like savage who struggled for existence with the megatherium, the fossil bear, or the formidable saber-toothed tiger of Port Kennedy.

Smeared with clay, weary, full of misgivings of the caving in of the trench or some unexpected obstruction, we toiled on by candlelight; the more thrilled with excitement the deeper we dug, until at last all anxiety ended when the pickaxe clanged on solid rock. We were done. It was over. We had penetrated for the first time this region of discovery to its uttermost limit, and had found, in the thick red interval below the culture layers of the surface, nothing but bats, snails, and rabbits. Here, where the primitive savage must have left

his sign if he existed, there was no primitive savage, no trace of humanity. The human evidence began and ended with the layers above. They stood for the builders of the ruins — a people who, judged by the potsherds of the layer, had arrived equipped with the art of making pottery, who had not, therefore, developed their culture in Yucatan, but had brought it with them from somewhere else. They represented an invasion of the peninsula fairly in accord with the Maya annals — something about a thousand or fifteen hundred years old; modern as compared with humanity in Europe, that was all. It had been suspected, but we had presented direct evidence on the subject for the first time.

This, then, was the testimony of the cave at Oxkintok. Let it stand for all the twenty-nine caves explored; since all, one after another, expressed the same fact more or less clearly as they were more or less fit for excavation. For the reasons stated in my book, "The Hill Caves of Yucatan,"[1] we were satisfied; with this proof in our hands the work was done. Defeat would have been to fail to find caves favorable for excavation. But we had found them. We had been eminently successful; and though to make assurance doubly sure we pushed on, and continued to examine caves that always repeated and never contradicted what we had already learned, the work had lost its zest. What remained were glimpses of rare and wondrous beauty that rewarded us at these places; such a sight as we saw at Actun Xpukil (cave of mice), where rotunda after rotunda, lit from above and overgrown with banana groves, opened downward by what seemed subterranean valleys and mountains; as at Xabaka (cave of the coal-black water), where the dark pool lay in the gloom of an immense chamber reached by a chasm overhung with trees and ferns, and yawning from several sunny little recesses haunted by bees; like Xkokikan (the cave of serpents), where Indians told of intertwined masses of snakes writhing at the bottom of a gulf; or like Actun Benado, where the tinted walls of an immense rotunda, lit from above, rose about you like the complex vaultings of a gothic cathedral on whose walls Indians had carved the figures of animals.

But of all the fair sights of Yucatan, fairest of all and last to be forgotten, is beautiful Loltun. Rock of flowers indeed! where, like the

[1] The Hill Caves of Yucatan; or, A Search for Evidence of Man's Antiquity in the Caverns of Central America. Philadelphia: J. B. Lippincott Co., 1896.

FIG. 5. ACTUN XPUKIL. (*Cave of Mice.*)

Actun Xpukil (*Cave of Mice*) is in the mountains, two miles west of the *hacienda* of Chalcetok, Yucatan, and four miles from the ruined city of Oxkintok; one of the largest and most beautiful caverns in Yucatan, containing fifty-nine stone water-dishes and many relics of the builders of the neighboring ruins. View from the first rotunda into the second rotunda, showing the effect of the skylight upon vegetation underground. Palm trees flourish in the cooler air. Alamo roots reach the cave floor from the brink of the skylight eighty to one hundred feet above.

FIG. 6. SKYLIGHT IN THE WATER CAVE OF OXKINTOK.

The banana trees are growing on a heap of fallen limestone fragments, many of which have been hollowed for water-dishes or mortars, or dressed square for wall building by the makers of the neighboring ruins. No trace of the tools was discovered.

enchanted garden that Aladdin saw, doomed to vanish at an ill-chosen word, groves rustled under ground, and by the quiet light of the sky windows fringed with forest, it seemed always afternoon. A bluish reflection made the air appear like liquid. By the great vaults where cool drops fell, we seemed to be walking under the sea at places where enormous fish, not stranger in shape than the stalagmites, might swim from labyrinths of coral. Here we were neither in the heavens above, or on the earth beneath, but by the waters under the earth ; and the airs that drew cool through the underground gardens were one of the delights of Paradise upon those scorching days.

When the cavern had yielded its secret after ten days of toil, as we were about to say farewell to it for the last time, its superhuman beauty came irresistibly upon us. Then the great chasms and galleries leading into an unknown blackness had lost their terror. Then stalagmites, that rose in forms of men and beasts from the floor, seemed to wear gentle smiles. In the pleasant air the birds chirped alluringly from about the skylights, while from under the blue arches seemed to come a rustle of leaves that repeated the whisper — here is rest. A vague regret, a confusion of motives stirred us. We felt the power of an enchantment potent to beguile us, like the lotus eaters, to forget the way home.

We have been told that our expedition was a failure because we did not contrive to bring back a store of vases painted with hieroglyphs, remarkable objects of jade, blades of obsidian, or even manuscripts. Forgive us if we did not return laden with these things, if, in the first place, we did not go to Yucatan to find them. Neither did we go there to find fossil man, but the truth. To defend our work from the charge of failure is to say that we have cited for the first time the evidence of caves to set a limit to the speculations of archæologists in Yucatan ; that by a newly applied test of much importance we have fixed a reasonable antiquity for the ruins and the builders of the ruins, and that by proof rather than guesswork we have shown that the culture of the Mayas was not developed in Yucatan, but brought from abroad.

As far as the geological antiquity of the human race is concerned, shall we not infer that Yucatan, that center of archæological interest, has been fairly eliminated from the field of search, and that from our labor it may be concluded, not unjustly, that if you would find fossil man you must look for him elsewhere?

RESULTS OF TESTS MADE IN THE ENGINEERING LABORATORIES.

VIII.

Received May 20, 1897.

Applied Mechanics.

Tests on Bolted Joints.

The fourteen tests on bolted joints given in the following summary were planned with the aim of finding the effect on the efficiency of the joint and on the tensile strength of the net section of plate, of increasing the compression per square inch in front of the rivets.

All the specimens were made from the same sheet of boiler plate of a tensile strength of 68,000 pounds per square inch. The bolts were of machine steel of 96,300 pounds tensile strength per square inch. The holes in the plate were drilled and rimmed, and the bolts were turned so as to be an easy driving fit with a machinist's hammer.

Micrometer readings of the stretch of the joints were taken from both the top and the bottom sides, there being two sets of measuring points on each side.

Details and cuts of the first eight joints were printed in the Technology Quarterly, Vol. IX, 1896, pages 171–180 (*Results of Tests, V*). Joints 9 and 10 were made with three bolts, joints 11 and 12 with two bolts, and joints 13 and 14 with one bolt.

Joints Nos. 2, 11, 12, 13, and 14 failed by the shearing of the bolts.

The broken joints are shown by the half-tone cuts, Figures 1–5.

SUMMARY OF TESTS.

Number of joint.	Size of bolts.	Pitch.	Thickness of plate.	Width or joint.	Area of net section. (Sq. ins.)	Maximum load.	Maximum tension on net section. (Lbs. per sq. in.)	Maximum shear on bolts. (Lbs. per sq. in.)	Maximum compression. (Lbs. per sq. in.)	Average thickness of plate in front of bolts at fracture.	Reduction of area. (Net section.)	Efficiency of joint.
1	1"	2 "	.43"	6.01"	1.62	102,000	63,100	38,500	105,400	.49"	31%	58%
2	1"	2 "	.43"	6.00"	1.61	101,100	62,600	38,100	104,500	.49"	15%	57%
3	1"	2 1/8"	.43"	7.69"	2.18	137,000	62,900	38,000	121,000	.51"	28%	61%
4	1"	2 1/16"	.43"	7.70"	2.18	136,000	62,300	37,700	120,500	.52"	30%	60%
5	1 "	3 1/8"	.44"	9.76"	2.97	179,500	60,400	38,100	136,000	.57"	28%	62%
6	1 "	3 1/8"	.44"	9.76"	2.97	180,700	60,800	38,300	136,900	.58"	23%	62%
7	1 1/8"	4 "	.45"	12.00"	3.88	238,500	61,500	39,900	158,600	.59"	25%	65%
8	1 1/8"	4 "	.45"	12.00"	3.88	225,500	58,100	37,600	148,600	.56"	26%	62%
9	1 1/8"	4 1/8"	.45"	14.64"	4.90	292,000	59,600	39,700	173,100	.68"	25%	65%
10	1 1/8"	4 1/8"	.45"	14.64"	4.90	292,000	59,600	39,700	173,100	.66"	22%	65%
11	1 1/8"	5 1/8"	.45"	11.55"	3.96	194.000	49,000	32,700	156,700	.68"	6%	55%
12	1 1/8"	5 1/8"	.45"	11.55"	3.97	197,700	49,800	33,300	160,800	.68"	7%	56%
13	1 1/8"	....	.45"	5.54"	1.87	96,300	51,400	32,400	155,600	.66"	10%	57%
14	1 1/8"	....	.44"	5.51"	1.82	96,700	53,200	32,600	159,800	.66"	8%	59%

No. 9. TEST ON BOLTED JOINT. (FIGURE 1.)

Date, February 25, 1897.

Loads.	North Side. Top. 1	North Side. Top. 2	North Side. Bottom. 1	North Side. Bottom. 2	Mean.	Difference.	South Side. Top. 1	South Side. Top. 2	South Side. Bottom. 1	South Side. Bottom. 2	Mean.	Difference.	Average difference.	Total difference.
5,000	.1314	.1315	.1287	.1287	.1301		.0532	.0532	.0534	.0532	.0532			
25,000	.1367	.1365	.1327	.1326	.1346	.0045	.0532	.0532	.0526	.0526	.0529	.0003	.0021	.0021
45,000	.1420	.1418	.1382	.1380	.1400	.0054	.0525	.0525	.0521	.0521	.0523	.0006	.0024	.0045
65,000	.1502	.1503	.1470	.1470	.1486	.0086	.0523	.0520	.0520	.0520	.0521	.0002	.0042	.0087
Load dropped off for 21 hours.														
65,000	.0491	.0491	.0487	.0487	.0489			.1604		.1566	.1585			
85,000	.0450	.0450	.0450	.0449	.0450	.0039	.1852	.1852	.1819	.1819	.1835	.0250	.0106	.0193
105,000	.0376	.0376	.0376	.0376	.0375	.0075	.2390	.2390	.2352	.2355	.2372	.0537	.0231	.0424
125,000	.0370	.0370	.0383	.0384	.0377	.0002	.2647	.2645	.2619	.2620	.2633	.0261	.0132	.0556
145,000	.0526	.0524	.0577	.0577	.0551	.0174	.3325	.3324	.3352	.3350	.3338	.0705	.0439	.0995
165,000	.0869	.0869	.0912	.0914	.0891	.0340	.3950	.3950	.3948	.3948	.3949	.0611	.0476	.1471
185,000	.1520	.1522	.1552	.1552	.1539	.0648	.4846	.4845	.4832	.4835	.4840	.0891	.0769	.2240
292,000	Maximum load.													

Size of bolts	1¼"	Maximum shear per sq. in. on bolts	39,700 lbs.
Pitch of bolts	4⅛"	Maximum compression per sq. in. on plate	173,100 lbs.
Thickness of plate	.45"	Average thickness of plate in front of bolts at fracture	.68"
Width of plate	14.64"	Reduction of area net section of plate,	25%
Area net section of plate	4.90 sq. in.	Efficiency of joint	65.2%
Maximum tension per sq. in. on net section of plate	59,600 lbs.		

No. 10. TEST ON BOLTED JOINT. (FIGURE 2.)

Date, March 1, 1897.

Loads.	North Side.				Mean.	Difference.	South Side.				Mean.	Difference.	Average difference.	Total difference.
	Top.		Bottom.				Top.		Bottom.					
	1	2	1	2			1	2	1	2				
5,000	.0367	.0365	.0415	.0418	.0391		.0336	.0333	.0284	.0282	.0309			
25,000	.0373	.0375	.0395	.0392	.0384	.0007	.0426	.0428	.0344	.0343	.0385	.0076	.0035	
45,000	.0379	.0378	.0395	.0393	.0388	.0004	.0517	.0519	.0421	.0420	.0469	.0084	.0044	.0079
65,000	.0343	.0344	.0355	.0357	.0350	.0038	.0621	.0622	.0525	.0526	.0574	.0105	.0034	.0113
85,000	.0341	.0340	.0358	.0357	.0349	.0001	.0724	.0727	.0634	.0633	.0680	.0106	.0053	.0166
	Load dropped off 17 hours.													
35,000	.0204	.0201	.0277	.0279	.0240		.0824	.0823	.0752	.0753	.0788			
105,000	.0268	.0270	.0349	.0348	.0309	.0069	.0953	.0954	.0888	.0890	.0921	.0133	.0101	.0267
115,000	.0199	.0202	.0277	.0278	.0239	.0070	.1470	.1470	.1404	.1405	.1437	.0516	.0223	.0490
125,000	.0207	.0208	.0285	.0286	.0247	.0008	.1487	.1489	.1422	.1423	.1455	.0018	.0013	.0503
135,000	.0198	.0200	.0277	.0278	.0238	.0009	.1583	.1585	.1522	.1523	.1553	.0098	.0045	.0548
145,000	.0169	.0169	.0247	.0247	.0208	.0030	.1790	.1790	.1728	.1730	.1760	.0207	.0089	.0637
155,000	.0108	.0110	.0191	.0192	.0150	.0058	.2141	.2140	.2081	.2082	.2111	.0351	.0147	.0784
165,000	.0075	.0076	.0158	.0157	.0117	.0033	.2400	.2400	.2340	.2342	.2371	.0260	.0114	.0998
175,000	.0045	.0046	.0131	.0129	.0088	.0029	.2676	.2674	.2625	.2625	.2650	.0279	.0125	.1123
	Load dropped off 3 hours.													
175,000	.0851	.0850	.0943	.0943	.0897		.2922	.2919	.2804	.2803	.2862			
185,000	.0850	.0848	.0943	.0940	.0895	.0002	.3160	.3160	.3047	.3047	.3104	.0242	.0120	.1243
195,000	.0845	.0842	.1040	.1042	.0942	.0047	.3526	.3526	.3425	.3425	.3476	.0372	.0220	.1463
292,000	Maximum load.													

Size of bolts	$1\frac{1}{4}''$	Maximum shear per sq. in. on bolts	39,700 lbs.
Pitch of bolts	$4\frac{7}{8}''$	Maximum compression per sq. in. on plate	173,100 lbs.
Thickness of plate	.45″	Average thickness of plate in front of bolts at fracture	.66″
Width of plate	14.64″	Reduction of area net section of plate,	22%
Area net section of plate	4.90 sq. in.	Efficiency of joint	65.2%
Maximum tension per sq. in. on net section of plate	59,600 lbs.		

FIG. 1. BOLTED JOINT NO. 9.

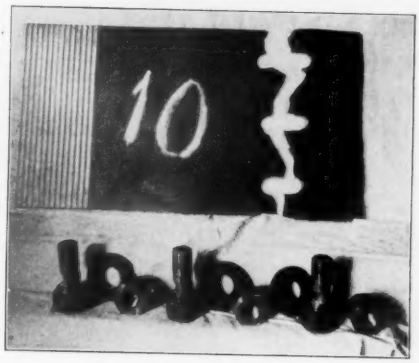


FIG. 2. BOLTED JOINT NO. 10.

No. 11. TEST ON BOLTED JOINT. (Figure 3.)

Date, March 3, 1897.

Loads.	North Side. Top. 1	North Side. Top. 2	North Side. Bottom. 1	North Side. Bottom. 2	Mean.	Difference.	South Side. Top. 1	South Side. Top. 2	South Side. Bottom. 1	South Side. Bottom. 2	Mean.	Difference.	Average difference.	Total difference.
5,000	.2657	.2655	.2713	.2710	.2684		.0972	.0972	.1021	.1019	.0996			
25,000	.2734	.2736	.2785	.2782	.2759	.0075	.1000	.1000	.1041	.1039	.1020	.0034	.0055	.0055
45,000	.2907	.2904	.2939	.2938	.2922	.0163	.0978	.0976	.1011	.1013	.0995	.0025	.0069	.0124
65,000	.3025	.3028	.3127	.3127	.3077	.0155	.0997	.0797	.1030	.1030	.1014	.0019	.0087	.0211
	Load dropped off for 21 hours.													
65,000	.1090	.1093	.1119	.1119	.1105		.3128	.3128	.3148	.3150	.3138			
85,000	.1435	.1431	.1448	.1449	.1441	.0336	.3191	.3194	.3204	.3203	.3198	.0060	.0198	.0409
105,000	.2173	.2173	.2159	.2162	.2167	.0726	.3657	.3657	.3664	.3665	.3661	.0463	.0595	.1004
125,000	.3325	.3325	.3316	.3316	.3321	.1154	.4633	.4635	.4648	.4646	.4391	.0730	.0942	.1946
145,000	.4876	.4876	.4900	.4900	.4888	.1567	.6050	.6050	.6100	.6100	.6075	.1684	.1626	.3572
194,000	Maximum load.													

Size of bolts	$1\frac{3}{8}''$	Maximum compression per sq. in. on plate	156,700 lbs.
Pitch of bolts	$5\frac{3}{4}''$	Average thickness of plate in front of bolts at fracture	.68″
Thickness of plate	.45″	Reduction of area net section of plate,	6%
Width of plate	11.55″	Average width of bolt holes at fracture,	1.46″
Area net section of plate	3.96 sq. in.	Average length of bolt holes at fracture,	$2.\frac{3}{8}''$
Maximum tension per sq. in. on net section of plate	49,000 lbs.	Efficiency of joint	55%
Maximum shear per sq. in. on bolts	32,700 lbs.		

No. 12. TEST ON BOLTED JOINT. (FIGURE 4.)

Date, March 9, 1897.

Loads.	North Side.				Mean.	Difference.	South Side.				Mean.	Difference.	Average difference.	Total difference.
	Top.		Bottom.				Top.		Bottom.					
	1	2	1	2			1	2	1	2				
5,000	.1009	.1010	.1837	.1834	.1422		.1075	.1076	.1719	.1719	.1397			
25,000	.1043	.1040	.1807	.1803	.1423	.0001	.1170	.1172	.1761	.1762	.1466	.0069	.0035	.0035
45,000	.1000	.1000	.1738	.1739	.1369	.0054	.1432	.1432	.1995	.1995	.1713	.0247	.0097	.0132
55,000	.0966	.0968	.1695	.1693	.1331	.0038	.1591	.1589	.2149	.2146	.1869	.0156	.0059	.0191
65,000	.0929	.0926	.1648	.1648	.1288	.0043	.1829	.1827	.2376	.2377	.2102	.0233	.0095	.0286
75,000	.0943	.0942	.1655	.1655	.1299	.0011	.1875	.1875	.2403	.2403	.2139	.0037	.0024	.0310
	Load dropped off for 3 hours.													
75,000	.0922	.0923	.1622	.1620	.1272		.1928	.1924	.2408	.2410	.2167			
85,000	.0935	.0937	.1639	.1640	.1288	.0016	.2148	.2150	.2678	.2674	.2413	.0246	.0131	.0441
95,000	.1020	.1021	.1716	.1718	.1369	.0081	.2470	.2470	.2993	.2989	.2730	.0317	.0199	.0640
105,000	.1295	.1296	.1982	.1986	.1640	.0271	.2883	.2879	.3392	.3390	.3136	.0406	.0339	.0979
115,000	.1790	.1790	.2472	.2469	.2130	.0490	.3437	.3441	.3937	.3935	.3688	.0552	.0521	.1500
125,000	.2363	.2345	.3040	.3027	.2693	.0563	.3995	.3980	.4487	.4480	.4235	.0547	.0555	.2055
197,700	Maximum load.													

Size of bolts	1⅛″	Maximum compression per sq. in. on plate	160,800 lbs.
Pitch of bolts	5¾″	Average thickness of plate in front of bolts at fracture	.68″
Thickness of plate	.45″	Reduction of area net section of plate,	7%
Width of plate	11.55″	Average width of bolt holes at fracture,	1.45″
Area net section of plate	3.97 sq. in.	Average length of bolt holes at fracture,	2.27″
Maximum tension per sq. in. on net section of plate	49,800 lbs.	Efficiency of joint	56%
Maximum shear per sq. in. on bolts	33,300 lbs.		

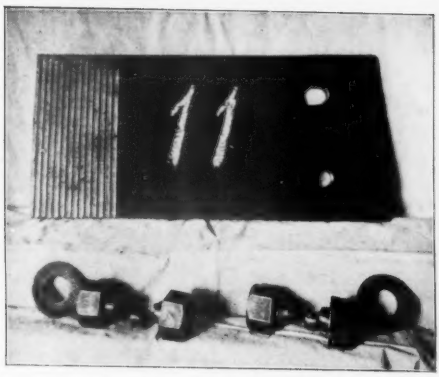


FIG. 3. BOLTED JOINT NO. 11.

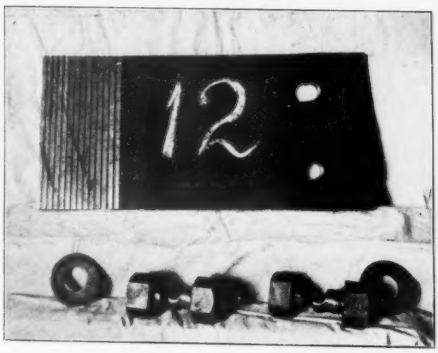


FIG. 4. BOLTED JOINT NO. 12.

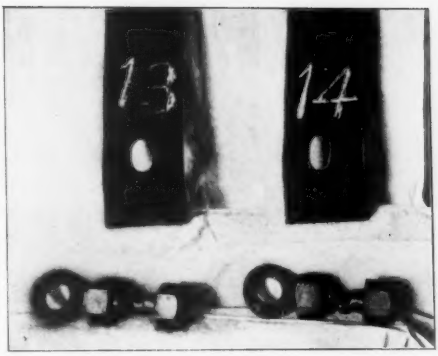


FIG. 5. BOLTED JOINTS NOS. 13 AND 14.

Wrought Iron Pipe Columns.

SUMMARY OF TESTS. March, 1896.

Date of Test.	Nominal size of pipe.	Inside diameter.	Outside diameter.	Diameter of flanges.	Length of inside of flanges.	Gauge length.	Maximum load.	Area of cross section.	Maximum load per sq. in.	Compression modulus of elasticity.	$\frac{l}{\rho}$, or ratio of length to radius of gyration.
	In.	In.	In.	In.	In.	In.	Lbs.	Sq. in.	Lbs.		
March 31, 1896	2	2.06	2.37	7	69/64	51	30,000	1.08	27,800	24,300,000	88.8
March 30, 1896	2	2.04	2.39	7	69/64	51	29,800	1.22	24,500	22,200,000	89.1
March 26, 1896	2½	2.50	2.89	8	93/64	86	34,500	1.65	20,900	25,200,000	98.1
March 27, 1896	2½	2.48	2.88	8	93/64	86	37,000	1.68	22,000	25,900,000	98.4
March 10, 1896	3	3.06	3.44	8	93/64	86	45,500	1.94	23,500	27,700,000	81.4
March 12, 1896	3	3.09	3.48	8	93/64	86	51,000	2.01	25,300	25,100,000	80.5
March 24, 1866	3½	3.60	4.00	9	105/64	100.5	55,000	2.39	23,000	25,200,000	78.2
March 25, 1896	3½	3.59	3.99	9	105/64	100.5	65,000	2.39	27,200	24,600,000	78.5
March 16, 1896	4	4.07	4.53	9	117 7/16	100 5	80,000	3.11	25,700	25,800,000	77.1
March 20, 1896	4	4.09	4.50	9	117 7/16	100.5	69,000	2.76	25,000	24,900,000	77.3

The above ten columns were tested with ordinary cast iron flange couplings screwed on the ends.

SUMMARY OF TESTS. October and November, 1896.

Date of Test.	Nominal size of pipe.	Inside diameter.	Outside diameter.	Length of column.	Gauge length.	Limits of loads used in calculation of modulus of elasticity.	Compression used in calculation of modulus of elasticity.	Maximum load.	Area of cross section.	Maximum load per sq. in.	Compression modulus of elasticity.	$\frac{l}{\rho}$, or ratio of length to radius of gyration.
	Ins.	Ins.	Ins.	Ft. Ins.	Ins.	Lbs.	Ins.	Lbs.	Sq. Ins.	Lbs.		
Nov. 17, 1896	4	4.06	4.50	8, 0	80	5,000– 55,000	.0565	92,000	2.96	31,100	23,900,000	63.4
Nov. 18, 1896	4	4.13	4.52	8, 0	80	5,000– 45,000	.0520	78,000	2.65	29,400	23,300,000	62.7
Nov. 16, 1896	4	4.07	4.51	10, 0 1/16	100	5,000– 55,000	.0687	85,000	2.97	28,700	24,500,000	79.1
Nov. 19, 1896	4	4.06	4.50	10, 0	100	5,000– 45,000	.0556	81,700	2.96	27,600	24,300,000	79.2
Nov. 2, 1896	4	4.09	4.50	12, 0	120	5,000– 35,000	.0480	75,000	2.77	27,100	27,100,000	94.7
Nov. 20, 1896	4	4.12	4.48	12, 0	120	5,000– 45,000	.0719	77,000	2.43	31,700	27,500,000	94.6
Nov. 10, 1896	5	5.04	5.52	9, 11 15/16	100	5,000– 65,000	.0578	118,000	3.98	29,600	26,100,000	54.2
Nov. 11, 1896	5	5.05	5.56	10, 0	100	5,000– 65,000	.0538	122,000	4.25	28,700	26,200,000	63.9
Oct. 21, 1896	5	5.03	5.53	12, 0	100	5,000– 65,000	.0545	115,000	4.15	27,700	26,500,000	77.1
Oct. 26, 1896	5	5.18	5.57	12, 0	120	5,000– 65,000	.0800	103,500	3.29	31,400	27,300,000	75.7
Nov. 25, 1896	5	5.11	5.54	12, 0 1/16	120	0– 80,000	.1083	112,000	3.60	31,100	24,600,000	76.4
Nov. 4, 1896	5	5.10	5.56	14, 10 5/16	120	5,000– 45,000	.0437	112,000	3.85	29,100	28,500,000	94.7
Nov. 5, 1896	5	5.10	5.57	14, 11 5/16	120	5,000– 55,000	.0604	116,000	3.94	29,400	25,200,000	95.3
Nov. 9, 1896	6	6.15	6.63	9, 11 1/16	100	5,000– 85,000	.0588	143,000	4.82	29,700	28,200,000	53.1
Nov. 12, 1896	6	6.17	6.64	10, 0 5/16	100	5,000–105,000	.0791	145,000	4.73	30,700	26,700,000	53.2
Oct. 22, 1896	6	6.18	6.63	12, 0	120	5,000– 45,000	.0405	.....	4.53	.....	26,200,000	63.6
Oct. 23, 1896	6	6.13	6 65	12, 0	120	5,000– 65,000	.0542	145,000	5.22	27,800	25,500,000	63.7
Nov. 25, 1896	6	6.17	6.63	12, 0	120	25,000– 85,000	.0618	142,000	4 63	30,700	25,200,000	63.6
Nov. 6, 1896	6	6.23	6.67	15, 0	120	5,000– 85,000	.0814	145,000	4.46	32,500	26,500,000	78.9
Nov. 7, 1896	6	6.19	6.63	15, 0	120	20,000– 70,000	.0525	132,000	4.43	29,800	25,800,000	79.4

The above twenty columns had the ends turned off square in a lathe, and were supported on cast iron caps.

All the above columns were tested in the same manner as the spruce columns already described in Technology Quarterly, Vol. VIII, 1895, pp. 219-247.

Torsion Tests.

TORSION TESTS ON BURDEN'S BEST WROUGHT IRON, 2″ DIAMETER.

Number of test.	Date, 1896–1897.	Diameter of cross section. (Ins.)	Distance between jaws. (Ins.)	Gauged length. (Ins.)	Elastic limit. (In. lbs.)	Outside fiber stress at elastic limit. (Lbs. per sq. in.)	Maximum twisting moment. (In. lbs.)	Apparent outside fiber stress as calculated from maximum twisting moment. (Lbs. per sq. in.)	Limits of loads for calculating shearing modulus of elasticity. In. lbs.)	Angle of twist for difference of loads used in calculating shearing modulus of elasticity.	Shearing modulus of elasticity. (Lbs. per sq. in.)	Number of turns between jaws at fracture.	Turns per foot between jaws at fracture.	Time of breaking after passing elastic limit. (Min.)
										° ′ ″				
1	Oct. 23	2.01	63.8	40.0	18,000	11,300	85,050	53,300	3,600–18,000	1, 44, 00	11,300,000	9.50	1.79	30
2	Oct. 28	2.01	59.0	40.0	21,600	13,600	86,400	54,200	3,600–21,600	2, 14, 30	11,500,000	8.62	1.76	..
3	Oct. 29	2.01	53.0	36.0	21,600	13,600	84,510	53,000	3,600–21,600	2, 4, 30	11,200,000	6.87	1.56	..
4	Oct. 30	2.00	58.8	40.0	18,000	11,500	87,480	55,700	3,600–18,000	1, 48, 30	11,600,000	8.40	1.71	44
5	Oct. 31	2.00	65.5	40.0	18,000	11,500	85,410	54,400	3,600–14,400	1, 21, 30	11,600,000	8.52	1.56	..
6	Nov. 16	2.01	60.2	40.0	18,000	11,300	85,590	53,700	3,600–14,400	1, 23, 0	11,200,000	8.82	1.75	48
7	Nov. 18	2.02	58.5	36.0	21,600	13,400	85,140	52,600	3,600–14,400	1, 12, 20	11,300,000	8.05	1.65	39
8	Nov. 19	2.00	57.0	36.0	21,600	13,800	82,650	52,600	3,600–14,400	1, 14, 10	11,500,000	7.31	1.54	35
9	Nov. 20	2.02	57.8	40.0	21,600	13,400	86,580	53,500	3,600–14,400	1, 21, 10	11,200,000	8.84	1.77	..
10	Dec. 1	2.02	59.5	40.0	18,000	11,100	86,040	53,200	3,600–14,400	1, 21, 0	11,200,000	8.61	1.74	40
11	Dec. 3	2.02	60.0	40.0	19,800	12,200	87,840	54,300	3,600–14,400	1, 20, 30	11,300,000	8.93	1.79	40
12	Dec. 5	2.02	60.0	40.0	21,600	13,400	88,200	54,400	3,600–14,400	1, 21, 0	11,200,000	8.48	1.70	42
13	Dec. 8	2.01	53.3	36.0	21,600	13,600	87,480	54,900	3,600–14,400	1, 14, 10	11,300,000	7.85	1.77	35
14	Dec. 10	2.01	59.5	40.0	19,800	12,400	83,970	52,700	3,600–14,400	1, 21, 40	11,400,000	8.01	1.62	..
15	Dec. 11	2.01	59.5	40.0	18,000	11,400	84,780	53,200	3,600–14,400	1, 22, 30	11,200,000	8.32	1.68	40
16	Dec. 15	2.03	61.0	40.0	19,800	12,100	83,520	50,900	3,600–14,400	1, 20, 20	11,100,000	8.98	1.77	..
17	Feb. 26	2.00	63.0	40.0	19,800	12,600	84,050	53,500	3,600–14,400	1, 20, 30	11,700,000	9.24	1.76	41
18	Mar. 2	2.02	60.3	40.0	19,800	12,200	85,950	53,100	3,600–14,400	1, 21, 20	11,200,000	7.94	1.58	45
19	Mar. 3	2.01	60.0	40.0	18,000	11,300	84,600	53,100	3,600–14,400	1, 21, 10	11,400,000	8.62	1.72	..
20	Mar. 4	2.02	61.0	40.0	19,800	12,200	83,520	51,600	3,600–14,400	1, 22, 50	11,000,000	8.50	1.67	..
21	Mar. 5	2.00	60.5	40.0	19,800	12,600	86,040	54,000	3,600–14,400	1, 21, 40	11,600,000	8.80	1.75	..
22	Mar. 8	2.01	51.0	36.0	23,400	14,700	85,680	53,700	3,600–14,400	1, 14, 0	11,300,000	7.35	1.73	33
23	Mar. 15	2.01	36.8	40.0	21,600	13,600	87,480	54,900	3,600–14,400	1, 20, 40	11,500,000	8.66	1.83	38.5
24	Mar. 16	2.01	47.8	30.0	21,600	13,600	85,860	53,900	3,600–14,400	1, 1, 30	11,300,000	7.24	1.82	32
25	Mar. 18	2.01	59.4	42.0	19,800	12,400	85,050	53,300	3,600–14,400	1, 25, 0	11,500,000	8.92	1.80	39
26	Mar. 19	2.01	60.9	42.0	21,600	13,600	86,400	54,200	3,600–14,400	1, 26, 20	11,300,000	8.75	1.73	45
27	Mar. 25	2.00	59.5	40.0	21,600	13,800	86,400	55,000	3,600–14,400	1, 21, 10	11,700,000	9.08	1.83	39
28	Apr. 6	2.01	58.5	40.0	23,100	14,500	85,650	53,700	3,600–14,400	1, 20, 40	11,500,000	8.30	1.70	55
29	Apr. 12	2.00	58.5	40.0	19,800	12,600	84,870	54,200	3,600–14,400	1, 19, 50	11,800,000	7.87	1 61	36
30	Apr. 13	2.01	58.3	40.0	21,600	13,600	87,300	54,800	3,600–14,400	1, 20, 40	11,500,000	9.45	1.94	40
31	Apr. 14	2.01	58.4	40.0	21,600	13,600	86,490	54,200	3,600–14,400	1, 18, 10	11,900,000	8.73	1.80	39
32	Apr. 22	2.01	58.4	40.0	21,600	13,600	87,120	54,600	3,600–14,400	1, 19, 50	11,600,000	8 09	1.67	..
33	Apr. 28	2.00	59.8	40.0	19,800	12,600	84,870	54,000	3,600–14,400	1, 20, 50	11,700,000	8.80	1.77	38

Notes. — After passing the elastic limit the specimens were all fractured in the following uniform manner: For 5 minutes the slowest speed was used, giving the power-end jaw a rotation at the rate of one turn in about 13.5 minutes; for the next five minutes a medium speed was used at the rate of one turn in about 5.5 minutes; then the specimen was fractured under the fastest speed at the rate of one turn in about 3.5 minutes.

After the completion of the first sixteen experiments the testing machine was lined up and carefully readjusted.

Specimen No. 18 broke at the scale-end jaw; No. 29 broke near the middle of the specimen; and all the remaining specimens broke at the power-end jaw.

LIBRARY

TORSION TESTS ON HARD BRASS WIRE.

Number of test.	Date, 1896.	Diameter of cross section. (Ins.)	Length of specimen between jaws. (Ins.)	Maximum twisting moment. (In. lbs.)	Number of turns between jaws at fracture.	Apparent maximum outside fiber stress. (Lbs. per sq. in.)	Average number of turns per inch.
1	Oct. 23	.081	12.0	8.0	3.5	76,700	.29
2	Oct. 23	.081	12.0	9.2	3.5	88,200	.29
3	Oct. 26	.086	12.9	8.7	3.3	69,700	.27
4	Oct. 29	.081	12.0	8.8	3.3	83,700	.27
5	Nov. 2	.083	10.0	9.2	2.5	82,000	.25
6	Nov. 4	.081	12.0	7.8	3.0	74,800	.25

NOTE. — This wire was of the same grade as that upon which the tension tests were made. (See page 387.)

TORSION TESTS ON COMPOSITION.

Proportions: Copper, 88%; Zinc, 2%; Tin, 10%. $\frac{1}{2}''$ and $\frac{5}{8}''$ bars.

Number of test.	Date, 1897.	Diameter of cross section. (Ins.)	Length of specimen between jaws. (Ins.)	Maximum twisting moment. (In. lbs.)	Number of turns between jaws at fracture.	Apparent maximum outside fiber stress. (Lbs. per sq. in.)	Average number of turns per inch.
1	Apr. 13	.516	9.0	1207	8.63	44,900	.96
2	Apr. 22	.515	9.5	1204	7.54	44,800	.79
3	Apr. 22	.514	9.5	1099	7.61	41,300	.80
4	Apr. 27	.517	9.5	1097	7.14	40,500	.75
5	Apr. 27	.528	9.5	1015	5.72	35,200	.60
6	Apr. 28	.525	9.5	1067	6.62	37,300	.70
7	Apr. 14	.635	9.5	2095	7.79	41,700	.84
8	Apr. 14	.633	9.5	2230	7.88	44,800	.83
9	Apr. 15	.631	9.5	2083	6.88	42,200	.72
10	Apr. 22	.638	9.5	2353	8.80	46,100	.93
11	Apr. 28	.638	9.4	1906	6.68	37,400	.70
12	Apr. 28	.632	9.4	2173	6.82	43,900	.73

TORSION TESTS ON ¼″ ROLLED REFINED IRON.

Number of test.	Date, 1897.	Diameter of cross section. (Ins.)	Length of specimen between jaws. (Ins.)	Maximum twisting moment. (In lbs.)	Number of turns between jaws at fracture.	Apparent maximum outside fiber stress. (Lbs. per sq. in.)	Average number of turns per inch.
1	Mar. 1	.253	12.0	196.8	18.50	61,600	1.54
2	Mar. 3	.256	12.0	194.2	18.31	59,200	1.53
3	Mar. 10	.257	12.0	195.0	16.44	58,400	1.37
4	Mar. 11	.254	12.0	199.7	16.94	61,900	1.41
5	Mar. 24	.255	12.0	191.0	16.31	58,000	1.36
6	Mar. 26	.254	12.0	191.0	12.85	59,400	1 07
7	Mar. 26	.254	12.0	205.0	19.00	63,700	1.58
8	Mar. 29	.253	12.0	200.0	19.95	62,600	1.66
9	Apr. 1	.253	12.0	202.0	18.97	63,400	1.58
10	Apr. 5	.254	10.0	205.0	15.00	63,700	1.50
11	Apr. 6	.253	10.0	205.0	16.75	63,700	1.68
12	Apr. 6	.255	10.0	198.0	17.00	60,800	1.70
13	Apr. 7	.259	12.0	190.0	16.05	55,100	1.34

TORSION TESTS ON ⅜″ ROLLED REFINED IRON.

Number of test.	Date, 1897.	Diameter of cross section. (Ins.)	Length of specimen between jaws. (Ins.)	Maximum twisting moment. (In lbs.)	Number of turns between jaws at fracture.	Apparent maximum outside fiber stress. (Lbs. per sq. in.)	Average number of turns per inch.
1	Feb. 25	.375	12.0	605	13.25	58,500	1.10
2	Mar. 4	.373	12.0	622	12.85	60,800	1.07
3	Mar. 5	.373	12.0	639	12.60	62,500	1.05
4	Mar. 10	.373	12.0	590	12.50	57,700	1.04
5	Mar. 11	.375	12.0	614	12.06	59,100	1.01
6	Mar. 15	.372	12.0	592	8.91	58,600	.74
7	Mar. 22	.378	12.0	654	9.09	61,700	.76
8	Mar. 23	.369	12.0	606	11.80	60,900	.98
9	Mar. 24	.374	12.0	600	12.80	58,400	1.07
10	Mar. 26	.373	12.0	639	11.85	62,200	.99
11	Mar. 29	.378	12.0	648	12.03	61,200	1.00
12	Apr. 1	.369	12.0	599	13.37	60,900	1.11
13	Apr. 5	.374	10.0	626	9.50	60,900	.95
14	Apr. 6	.377	10.0	625	8.50	59,500	.85
15	Apr. 6	.380	10.0	615	9.50	57,100	.95

TORSION TESTS ON COMMON IRON WIRE.

Length of specimen between jaws, 12.0 inches.

Number of test.	Date, 1896.	Diameter of cross section. (Ins.)	Maximum twisting moment. (In. lbs.)	Number of turns between jaws at fracture.	Apparent maximum outside fiber stress. (Lbs. per sq. in.)	Average number of turns per inch.
1	Nov. 4	.194	113.2	41.0	79,200	3.4
2	Nov. 5	.194	103.9	41.3	72,900	3.4
3	Nov. 6	.193	112.5	42.0	80,000	3.5
4	Nov. 11	.192	112.3	43.5	80,800	3.6
5	Nov. 11	.194	116.7	19.5	81,400	1.6
6	Nov. 12	.193	113.1	46.8	80,100	3.9
7	Nov. 13	.193	121.8	38.5	86,300	3.2
8	Nov. 13	.193	112.1	45.5	79,400	3.8
9	Nov. 16	.193	119.1	48.0	84,400	4.0
10	Nov. 16	.193	116.2	45.5	82,300	3.8
11	Nov. 18	.193	108.0	48.3	76,500	4.0
12	Nov. 18	.192	116.5	42.8	83,800	3.6
13	Nov. 18	.193	107.7	41.8	76,300	3.5
14	Nov. 18	.193	119.0	43.5	84,300	3.6
15	Nov. 18	.193	117.3	46.5	83,100	3.9
16	Nov. 18	.193	112.2	46.5	79,500	3.9

TORSION TESTS ON COMMON IRON WIRE.

Annealed at a dull red heat for 8 hours. Length of specimen between jaws, 12.0″.

Number of test.	Date, 1896.	Diameter of cross section. (Ins.)	Maximum twisting moment. (In. lbs.)	Number of turns between jaws at fracture.	Apparent maximum outside fiber stress. (Lbs. per sq. in.)	Average number of turns per inch.
1	Nov. 23	.193	110.6	50.0	78,400	4.2
2	Nov. 25	.193	94.6	47.7	67,000	4.0
3	Nov. 25	.194	95.5	53.9	66,600	4.5
4	Nov. 30	.193	95.4	42.3	67,600	3.5
5	Nov. 30	.193	95.8	47.3	67,900	3.9
6	Dec. 1	.194	99.0	38.8	69,000	3.2
7	Dec. 2	.192	96.0	55.3	69,000	4.6
8	Dec. 4	.194	95.2	42.3	66,400	3.5
9	Dec. 5	.194	98 3	57.8	68,600	4.8
10	Dec. 10	.194	97.5	47.0	68,600	3.9

NOTE. — This wire was from same coil as that from which the tests at top of page were made.

TORSION TESTS ON $\frac{1}{4}''$ BESSEMER STEEL WIRE, COPPERED FINISH.

Number of test.	Date, 1896–97.	Diameter of cross section. (Ins.)	Length of specimen between jaws. (Ins.)	Maximum twisting moment. (In. lbs.)	Number of turns between jaws at fracture.	Apparent maximum outside fiber stress. (Lbs. per sq. in.)	Average number of turns per inch.
1	Nov. 24	.250	12.0	242.6	25.0	79,000	2.0
2	Nov. 30	.250	12.0	252.2	22.8	82,200	1.9
3	Nov. 30	.249	12.0	247.5	27.3	81,700	2.3
4	Dec. 1	.249	12.0	238.5	27.5	78,700	2.3
5	Dec. 2	.250	12.0	248.0	25.3	80,800	2.1
6	Dec. 3	.250	12.0	243.6	18.5	79,400	1.5
7	Dec. 4	.249	12.0	243.0	24.0	80,200	2.0
8	Dec. 5	.250	12.0	243.3	24.3	79,300	2.0
9	Dec. 7	.250	12.0	246.0	25.3	80,200	2.1
10	Dec. 10	.249	12.0	246.7	25.0	81,400	2.1
11	Dec. 15	.250	12.0	244.7	26.0	79,800	2.1
12	Dec. 15	.250	12.0	236.6	21.4	77,100	1.8
13	Apr. 7	.250	12.0	249.0	24.1	81,400	2.0
14	Apr. 12	.249	12.0	248.0	29.7	81,800	2.5
15	Apr. 13	.250	9.0	261.0	20.3	85,300	2.3

TORSION TESTS ON $\frac{3}{8}''$ BESSEMER STEEL WIRE, COPPERED FINISH.

Length of specimen between jaws, 12.0 inches.

Number of test.	Date, 1897.	Diameter of cross section. (Ins.)	Maximum twisting moment. (In. lbs.)	Number of turns between jaws at fracture.	Apparent maximum outside fiber stress. (Lbs. per sq. in.)	Average number of turns per inch.
1	Feb. 25	.376	836.0	21.53	80,000	1.79
2	Feb. 26	.376	769.0	15.00	73,400	1.25
3	Mar. 1	.377	849.0	20.00	81,000	1.67
4	Mar. 3	.375	765.5	12.88	73,800	1.07
5	Mar. 4	.377	810.0	20.60	77,200	1.72
6	Mar. 4	.375	776.0	16.00	74,800	1.34
7	Mar. 5	.375	835.0	12.30	80,500	1.03
8	Mar. 10	.376	773.0	15 40	74,300	1.28
9	Mar. 11	.375	846 0	18 92	82,000	1.58
10	Mar. 15	.377	809.1	17.58	77,000	1.47
11	Mar. 22	.377	811.0	19.15	77,100	1.60
12	Mar. 23	.376	817.0	6.10	78 500	.51
13	Mar. 24	.377	829.0	19.36	78,800	1.61
14	Mar. 24	.375	803.0	21.71	77,300	1.81
15	Mar. 25	.377	843.0	23.78	80,300	1.98

TORSION TESTS ON ¼″ ANNEALED CAST STEEL.

(Usually known as "Tool Steel.")

Number of test.	Date, 1897.	Diameter of cross section. (Ins.)	Length of specimen between jaws. (Ins.)	Maximum twisting moment. (In. lbs.)	Number of turns between jaws at fracture.	Apparent maximum outside fiber stress. (Lbs. per sq. in.)	Average number of turns per inch.
1	Feb. 25	.246	12.0	288.9	21.15	98,600	1.76
2	Feb. 26	.246	12.0	277.9	24.60	95,500	2.05
3	Mar. 3	.249	12.0	296.7	19.16	97,600	1.60
4	Mar. 4	.245	12.0	290.5	24.08	100,900	2.01
5	Mar. 5	.248	12.0	271.0	17.56	90,300	1.46
6	Mar. 10	.248	12.0	275.1	17.13	92,300	1.43
7	Mar. 11	.247	12.0	327.7	12.90	111,300	1.08
8	Mar. 11	.249	12.0	299.5	19.75	98,300	1.65
9	Mar. 18	.248	13.4	281.9	23.69	94,400	1.77
10	Mar. 23	.244	12.0	267.0	14.00	93,600	1.17
11	Mar. 24	.246	12.0	290.0	23.33	99,000	1.94
12	Mar. 23	.249	12.0	326.0	11.35	109,700	.95
13	Mar. 26	.248	12.0	292.0	14.37	97,000	1.20
14	Mar. 29	.247	12.0	276.0	18.04	93,700	1.50
15	Apr. 1	.244	12.0	293.0	15.25	102,700	1.27

TORSION TESTS ON STUBBS' STEEL WIRE.

Number of test.	Date, 1896-97.	Diameter of cross section. (Ins.)	Length of specimen between jaws. (Ins.)	Maximum twisting moment. (In. lbs.)	Number of turns between jaws at fracture.	Apparent maximum outside fiber stress. (Lbs. per sq. in.)	Average number of turns per inch.
1	Nov. 24	.1840	6.0	93.2	6.8	72,600	1.1
2	Nov. 30	.1848	6.0	120.0	3.3	96,800	.6
3	Nov. 30	.1839	6.0	106.8	2.8	87,300	.5
4	Dec. 1	.1842	6.0	121.5	7.5	99,000	1.3
5	Dec. 2	.1841	6.0	105.0	7.3	85,600	1.2
6	Dec. 3	.1839	6.0	101.3	6.4	82,800	1.1
7	Dec. 4	.1851	6.0	121.0	3.8	97,000	.6
8	Dec. 5	.1840	6.0	115.7	8.6	94,600	1.1
9	Dec. 7	.1840	6.0	116.8	8.8	95,500	1.5
10	Dec. 7	.1840	6.0	115.1	6.3	94,100	1.1
11	Dec. 10	.1842	6.0	119.9	4.1	97,700	.7
12	Apr. 7	.1852	6.5	113.5	3.6	91,000	.6
13	Apr. 12	.1836	6.0	113.0	3.9	93,000	.7

TENSION TESTS ON REFINED IRON.

Number of test.	Date, 1896–97.	Specimen.	Diameter of cross section. (Ins.)	Area of cross section. (Sq. ins.)	Gauged length. (Ins.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Elastic elongation for difference of loads used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)	Elastic limit. (Lbs.)
1	Nov. 9	Refined iron.	1.02	.817	10.0	1,000–13,000	.0054	27,200,000	26,000
2	Nov. 10	Refined iron.	1.01	.801	10.0	1,000–13,000	.0054	27,700,000	26,000
3	Nov. 12	Refined iron.	1.01	.801	10.0	1,000–13,000	.0053	28,300,000	24,000
4	Nov. 23	Refined iron.	1.02	.817	10.0	1,000– 9,000	.0037	26,500,000	26,000
5	Nov. 30	Refined iron.	1.01	.801	10.0	1,000–13,000	.0056	26,800,000	24,000
6	Dec. 2	Refined iron.	1.02	.817	10.0	1,000–13,000	.0056	26,200,000	24,000
7	Dec. 7	Refined iron.	1.01	.801	10.0	1,000–13,000	.0053	28,300,000	24,000
8	Feb. 26	Refined iron.	1.02	.817	10.0	1,000–13,000	.0052	28,200,000	.....
9	Mar. 1	Refined iron.	1.02	.817	10.0	1,000–13,000	.0054	27,200,000	26,000
10	Apr. 17	Refined iron.	1.01	.801	10.0	1,000– 9,000	.0036	27,700,000	24,000
11	Apr. 28	Refined iron.	1.01	.801	10.0	1,000–13,000	.0058	25,800,000	24,000
12	Oct. 23	Refined iron.	.77	.466	10.0	500– 6,500	.0046	28,000,000	12,000
13	Oct. 24	Refined iron.	.74	.430	10.0	500– 6,500	.0047	29,700,000	12,000
14	Nov. 6	Refined iron.	.74	.430	10.0	500– 6,500	.0047	29,700,000	11,000
15	Nov. 9	Refined iron.	.76	.454	10.0				12,000
16	Nov. 25	Refined iron.	.76	.454	10.0	500– 6,500	.0048	27,600,000	14,000

TENSION TESTS ON REFINED IRON. — *Concluded.*

Number of test.	Elastic limit. (Lbs. per sq. in.)	Maximum load. (Lbs.)	Maximum load. (Lbs. per sq in.)	Area of fractured section. (Sq. ins.)	Reduction of area. (Per cent.)	Ultimate extension in gauged length. (Ins.)	Ultimate extension in gauged length. (Per cent.)	Remarks.
1	31,800	41,100	50,300	.679	16.9	1.28	12.8	Broke in upper jaw, outside of gauged length.
2	32,500	37,650	47,000	.636	20.6	.75	7.5	Broke at flaw.
3	30,000	40,400	50,400	.595	25.8	1.74	17.4	Broke at punch marks.
4	31,800	40,560	49,600	.622	23.9	1.74	17.4	Broke at punch marks.
5	30,000	40,220	50,200	.541	32 5	1.05	10.5	
6	29,400	41,230	50,500	.568	30.6	2.12	21.2	Broke at punch marks.
7	30,000	41,190	51,400	.568	29.2	1.81	18 1	Broke at punch marks.
8	.....	41,180	50,400	.650	20.4	1.31	13.1	Broke outside of gauged length.
9	31,800	42,000	50,200	.694	15.1	1.28	12.8	
10	30,000	38,550	48,100	.541	32.5	1.27	12.7	Broke outside of gauged length at a flaw.
11	30,000	40,560	50,600	.581	27.5	1.69	16.9	Broke at punch marks.
12	25,800	22,630	48,600	.221	52.6	2.65	26 5	
13	27,900	23,250	53,900	.264	38.6	2.57	25.7	
14	25,600	23,230	54,000	.353	18.0	1 59	15.9	Broke at lower punch marks.
15	26,400	22,470	49,500	.264	41.8	2.62	26.2	
16	30,900	24,280	53,500	.302	33.4	2.41	24.1	

TENSION TESTS ON BESSEMER STEEL WIRE.

Number of test.	Date, 1897.	Specimen.	Diameter of cross section. (Ins.)	Area of cross section. (Sq. ins.)	Gauged length. (Ins.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Elastic elongation for difference of loads used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)	Elastic limit. (Lbs.)	Elastic limit. (Lbs. per sq. in.)	Maximum load. (Lbs.)	Maximum load. (Lbs. per sq. in.)	Area of fractured section. (Sq. ins.)	Reduction of area. (Per cent.)	Remarks.
1	Mar. 8	Bessemer steel wire.	.1290	.01307	50.00	50–350	.....	30,000,000	...	.....	1,013	77,500	.00466	64.4	This wire was of the same grade as that used in the torsion tests on $\frac{1}{4}$" and $\frac{3}{8}$" Bessemer steel wire, coppered finish.
2	Mar. 8	Bessemer steel wire.	.1280	.01287	50.00	50–350	.0383	30,400,000	850	66,100	1,021	79,400	.00568	55.9	
3	Mar. 9	Bessemer steel wire.	.1288	.01303	50.00	50–350	.0373	30,900,000	890	68,300	1,010	77,500	.00503	61.4	
4	Mar. 11	Bessemer steel wire.	.1291	.01309	50.00	50–350	.0382	30,000,000	880	67,200	970	74,100	.00478	63.5	
5	Mar. 11	Bessemer steel wire.	.1283	.01293	50.00	50–350	.0394	29,500,000	860	66,500	996	77,000	.00554	57.1	The specimens buckled so badly when the rebound at fracture occurred, that it was not possible to measure the ultimate extension with accuracy. In tests 3, 4, and 5, the extension in 36" was measured as carefully as possible and found to be 1.1, 1.1, and .7 per cent. respectively.
6	Mar. 25	Bessemer steel wire.	.1283	.01293	50.00	50–350	.0387	30,000,000	900	69,600	1,021	79,000	.00554	57.1	
7	Mar. 29	Bessemer steel wire.	.1289	.01306	50.00	50–350	.0369	31,200,000	910	69,700	1,005	77,000	.00515	60.5	
8	Mar. 29	Bessemer steel wire.	.1281	.01289	50.00	50–350	.0398	29,200,000	920	71,400	1,043	80,900	.00466	63.9	
9	Mar. 31	Bessemer steel wire.	.1283	.01293	50.00	50–350	.0378	30,700,000	850	65,800	1,004	77,700	.00484	62 6	
10	Mar. 30	Bessemer steel wire.	.1286	.01299	50.00	50–350	.0373	31,000,000	890	68,500	1,000	77,000	.00478	63.2	

TENSION TESTS ON BESSEMER STEEL WIRE. (Coppered finish.)

Number of test.	Date, 1896-97.	Specimen.	Diameter of cross section. (Ins.)	Area of cross section. (Sq. ins.)	Gauged length. (Ins.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Elastic elongation for difference of loads used for calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)	Elastic limit. (Lbs.)	Elastic limit. (Lbs. per sq. in.)	Maximum load. (Lbs.)	Maximum load. (Lbs. per sq. in.)	Area of fractured section. (Sq. ins.)	Reduction of area of cross section. (Per cent.)	Remarks.
1	Dec. 2	Bessemer steel wire.	.1048	.00863	50.0	100–300	.0404	28,700,000	700	81,200	853.0	98,900	.00353	59.1	Broke outside of gauged length, at clamp.
2	Dec. 4	Bessemer steel wire.	.1047	.00861	50.0	50–350	.0629	27,700,000	740	86,000	795.0	92,300	.00363	57.8	This wire was of the same grade as that used in the torsion tests on ¼" and ⅜" Bessemer steel wire, coppered finish.
3	Dec. 7	Bessemer steel wire.	.1045	.00858	50.0	50–350	.0617	28,400,000	710	82,600	830.0	96,700	.00503	41.4	
4	Dec. 8	Bessemer steel wire.	.1045	.00858	50.0	50–350	.0617	28,400,000	700	81,600	807.5	94,200	.00385	55.1	
5	Dec. 8	Bessemer steel wire.	.1040	.00849	50.0	50–350	.0612	28,900,000	760	89,500	834.0	98,000	.00374	56.0	Inasmuch as the elastic limit was so near the maximum load and the reduction at the fracture was so short, it was not possible to measure the ultimate extension with accuracy.
6	Feb. 26	Bessemer steel wire.	.1050	.00866	50.0	50–350	.0642	27,000,000	690	79,700	815.0	94,120	.60442	49.0	
7	Mar. 1	Bessemer steel wire.	.1055	.00874	50.0	30–350	.0617	27,800,000	760	86,900	805.0	92,100	.00385	56.0	
8	Mar. 3	Bessemer steel wire.	.1050	.00866	50.0	50–350	.0593	29,200,000	740	85,500	807.0	93,200	.00396	54.3	
9	Mar. 4	Bessemer steel wire.	.1041	.00851	50.0	50–350	.0610	28,900,000	710	83,400	808.0	94,900	.00353	58.6	
10	Mar. 5	Bessemer steel wire.	.1049	.00864	50.0	50–350	.0614	28,300,000	750	86,800	796.0	92,100	.00374	56.7	
11	Mar. 18	Bessemer steel wire.	.1059	.00881	50.0	50–350	.0602	28,300,000	690	78,300	807.0	91,600	.00363	59.0	
12	Mar. 20	Bessemer steel wire.	.1048	.00863	50.0	50–350	.0609	28,600,000	690	80,000	787.0	91,200	.00363	57.9	
13	Mar. 25	Bessemer steel wire.	10.53	.00871	50.0	50–550	.0608	28,300,000	690	79,200	803.0	92,200	.00342	60.7	
14	Apr. 28	Bessemer steel wire.	10.41	.00851	50.0	50–350	.0593	29,700,000	710	83,400	795.0	93,400	.00363	57.3	

TENSION TESTS ON HARD BRASS WIRE.

Number of test.	Date, 1896.	Specimen.	Diameter of cross section. (Ins.)	Area of cross section. (Sq. ins.)	Gauged length. (Ins.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Elastic elongation for difference of loads used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)	Elastic limit. (Lbs.)	Elastic limit. (Lbs. per sq. in.)	Maximum load. (Lbs.)	Maximum load. (Lbs. per sq. in.)	Area of fractured section. (Sq. in.)	Reduction of area of cross section. (Per cent.)	Remarks.
1	Oct. 30	Hard brass wire.	.081	.00515	100 0	38–266	.3638	12,100,000	266	51,500	465.5	90,100	.00204	60.5	The elastic limit was not clearly defined in this kind of wire, hence it could only be roughly estimated from the stretch readings.
2	Oct. 31	Hard brass wire.	.081	.00515	100.0	38–228	.2663	13,800,000	228	44,100	465 5	90,100	.00283	45.3	
3	Nov. 16	Hard brass wire.	.081	.00515	100.0	38–228	.2834	13,000,000	228	44,200	460.0	89,300	.00255	50.5	
4	Nov. 16	Hard brass wire.	.081	.00515	100.0	38–228	.2838	13,000,000	228	44,200	458.5	89,000	.00255	50.5	
5	Nov. 17	Hard brass wire.	.081	.00515	100.0	40–240	.3091	12,600,000	280	54,300	457.0	88,700	.00204	60.4	
6	Nov. 19	Hard brass wire.	.081	.00515	100.0	40–240	.2997	13,000,000	240	46,600	474.5	92,100	.00246	52.2	
7	Nov. 20	Hard brass wire.	.081	.00515	100.0	40–240	.3045	12,800,000	240	46,600	471.0	91,400	.00292	43.3	
8	Nov. 21	Hard brass wire.	.081	.00515	100.0	40–240	.3007	12,900,000	240	46,600	472.0	91,600	.00237	53.9	
9	Nov. 23	Hard brass wire.	.081	.00515	100.0	40–200	.2137	14,500,000	200	38,800	471.5	91,500	.00246	52.2	
10	Nov. 23	Hard brass wire.	.081	.00515	100.0	40–240	.2989	13,000,000	240	46,600	456.0	88,500	.00221	57.2	
11	Nov. 25	Hard brass wire.	.081	00.515	100.0	40–200	.2382	13,000,000	200	38,800	473.0	91,800	.00174	66.3	
12	Nov. 30	Hard brass wire.	.081	.00515	100.0	40–240	.2911	13,300,000	240	46,600	469.0	91,000	.00221	57.2	

TENSION TESTS ON COLD-DRAWN STEEL WIRE, ELECTRICALLY WELDED.

Number of test.	Date, 1897.	Diameter of cross section. (Ins.)	Diameter of fractured section. (Ins.)	Area of original section. (Sq. ins.)	Area of fractured section. (Sq. ins.)	Reduction of area of cross section. (Per cent.)	Maximum load. (Lbs.)	Maximum load. (Lbs. per sq. in.)	Description of Specimen.	Location of Fracture.
1	Mar. 29	.1197	.071	.01125	.00396	64.8	1,006	89,400	Plain wire.	Near center.
2	Apr. 13	.1198	.077	.01127	.00466	58.7	972	86,230	Plain wire.	Near center.
3	Apr. 18	.1199	.075	.01129	.00442	60.9	956	84,670	Plain wire.	Near center.
4	Apr. 27	.1196	.085	.01124	.00568	49.5	997	88,750	Cross wire electrically welded at right angles.	Outside of weld.
5	Apr. 27	.1197	.075	.01125	.00442	60.7	993	88,240	Cross wire electrically welded at right angles.	Outside of weld.
6	Apr. 27	.1196	.075	.01124	.00442	60.7	993	88,380	Cross wire electrically welded at right angles.	Outside of weld.
7	Apr. 9	.1473	.103	.01704	.00833	51.1	1,792	105,200	Plain wire.	Near center.
8	Apr. 13	.1475	.112	.01709	.00985	42.3	1,900	111,200	Plain wire.	Near center.
9	Apr. 27	.1475	.105	.01709	.00866	49.3	1,875	109,700	Electrically welded butt joint.	Outside of weld.
10	Apr. 27	.1479	.095	.01718	.00709	58.7	1,650	96,040	Electrically welded butt joint.	Outside of weld.
11	Apr. 27	.1477	.111	.01713	.00968	43.8	1,860	108,600	Cross wire electrically welded at right angles.	Outside of weld.
12	Apr. 27	.1476	.108	.01711	.00916	46.5	1,875	109,600	Cross wire electrically welded at right angles.	Outside of weld.
13	Apr. 27	.1480	.094	.01720	.00694	59.7	1,765	102,600	Cross wire electrically welded at right angles.	Outside of weld.
14	Apr. 13	.1061	.073	.00884	.00419	52.7	982	111,100	Plain wire.	Near center.
15	Apr. 17	.1066	....	.00893	.....	....	892	99,940	Cross wire electrically welded at right angles.	At weld.
16	Apr. 17	.1063	.069	.00888	.00374	57.9	954	107,500	Cross wire electrically welded at right angles.	Outside of weld.
17	Apr. 17	.1066	....	.00893	.....	....	657	73,610	Cross wire electrically welded at right angles.	At weld.
18	Apr. 7	.1063	.052	.00888	.00212	76.1	482	54,300	Plain wire, annealed.	Near center.
19	Apr. 18	.1057	.061	.00878	.00292	66.7	493	56,180	Plain wire, annealed.	Near center.
20	Apr. 17	.1064	.050	.00889	.00196	77.9	486	54,660	Annealed wire with electrically welded cross wire.	Outside of weld.

Notes. — These specimens were welded by a patented process.
None of the specimens except Nos. 15 and 17 broke at the weld, and No. 15 nearly reached its ultimate strength before giving away. The other fractures took place at least 2″ from the weld in each case.
The length of specimen between jaws of testing machine was about 8″.

MISCELLANEOUS TENSION TESTS ON METALS.

Number of test.	Date, 1896-97.	Specimen.	Diameter of cross section. (Ins.)	Area of cross section. (Sq. ins.)	Gauged length. (Ins.)	Limits of loads used in calculation of modulus of elasticity. (Lbs.)	Average elastic elongation per 1,000 lbs. between limits used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)
1	Mar. 2	Stay bolt iron.	.86	.581	10.0	1,000-15,000	.00058	29,700,000
2	Mar. 3	Stay bolt iron.	.82	.528	10.0	....	.....	.....
3	Mar. 4	Stay bolt iron.	.74	.430	10.0	1,000-12,000	.00080	29,100,000
4	Mar. 4	Stay bolt iron.	.74	.430	10.0	1,000-11,000	.00079	29,400,000
5	Mar. 5	Stay bolt iron.	1.00	.785	10.0	1,000-22,000	.00044	28,900,000
1	Mar. 9	Open hearth steel.	.87	.595	10.0	1,000-13,000	.00059	28,500,000
2	Mar. 11	Open hearth steel.	.73	.419	10.0	1,000- 9,000	.00080	29,900,000
3	Mar. 16	Open hearth steel.	.72	.407	10.0	1,000- 9,000	.00084	29,200,000
4	Mar. 18	Open hearth steel.	.60	.283	10.0	500- 7,000	.00115	30,800,000
5	Mar. 20	Open hearth steel.	.60	.283	10.0	500- 7,000	.00118	30,000,000
1	Mar. 30	Soft Bessemer steel.	.73	.419	10.0	1,000-12,000	.00081	29,500,000
2	Apr. 2	Soft Bessemer steel.	.86	.581	10.0	1,000-12,000	.00063	27,300,000
3	Apr. 13	Soft Bessemer steel.	.61	.292	10.0	3,000- 7,000	.00123	27,900,000
4	Mar. 22	Soft Bessemer steel.	.73	.419	10.0	1,000- 7,000	.00085	28,100,000
5	Mar. 24	Soft Bessemer steel.	.60	.283	10.0	500- 8,000	.00120	29,500,000
1	Mar. 31	Hull rivet steel.	.74	.431	10.0	1,000-12,000	.00088	26,400,000
2	Apr. 1	Hull rivet steel.	.72	.407	10.0	1,000-13,000	.00087	28,300,000
3	Apr. 7	Hull rivet steel.	.85	.568	10.0	2,000-15,000	.00060	29,400,000
4	Apr. 13	Hull rivet steel.	.85	.568	10.0	2,000-16,000	.00060	29,400,000
1	Oct. 21	Burden best wrought iron.	.76	.454	10.0	500- 6,500	.00073	30,060,000
2	Oct. 22	Burden best wrought iron.	.76	.454	10.0	500- 6,500	.00078	28,140,000
3	Dec. 4	Burden best wrought iron.	.77	.466	10.0	500- 6,500	.00082	26,300,000
4	Dec. 7	Burden best wrought iron.	.76	.454	10.0	500- 6,500	.00073	30,060,000
1	Apr. 27	Composition.	.762	.456	8.00	.....	.....	.....
2	Apr. 27	Composition.	.772	.468	8.00	.....	.....	.....
3	Apr. 27	Composition.	.764	.458	8.00	.....	.....	.....
4	Apr. 27	Composition.	.756	.449	8.00	.....	.....	.....

MISCELLANEOUS TENSION TESTS ON METALS. — *Concluded.*

Number of test.	Elastic limit. (Lbs.)	Elastic limit. (Lbs. per sq. in.)	Maximum load. (Lbs.)	Maximum load. (Lbs. per sq. in.)	Area of fractured section. (Sq. ins.)	Reduction in area. (Per cent.)	Ultimate extension in gauged length. (Ins.)	Ultimate extension in gauged length. (Per ct.)	Remarks.
1	15,000	25,800	30,000	51,700	.363	37.5	2.27	22.7	
2	14,000	26,500	26,500	50,200	.273	48.2	2.41	24.1	
3	12,000	27,900	23,100	53,700	.238	44.8	2.47	24.7	
4	11,000	25,600	21,470	49,900	.302	29.8	1.44	14.4	Broke at a flaw.
5	22,000	28,000	39,540	50,300	.417	46.6	2.88	28.8	
1	13,000	21,900	25,730	43,300	.145	75.6	3.59	35.9	
2	9,000	21,500	18,810	44,900	.102	75.7	3.44	34.4	
3	9,000	22,100	18,840	46,300	.105	73.6	3.42	34.2	
4	7,000	24,800	13,230	46.800	.076	73.3	3.27	32.7	
5	7,000	24,800	13,200	46,700	.071	75.0	3.50	35.0	
1	12,000	28,700	23,510	56,200	.132	68.5	2.77	27.7	
2	17,000	29,300	32,940	56,700	.204	64.8	3.03	30.3	
3	9,000	30,800	17,941	61,400	.104	64.4	2.53	25.3	
4	12,000	28,700	23,650	56,500	.126	70.0	3.03	30.3	
5	8,000	28,300	17,830	63,100	.102	64.0	2.67	26.7	
1	12,000	27,900	24,380	56,680	.139	67.8	2.96	29.6	
2	13,000	31,900	24,700	60,700	.139	66.0	3.25	32.5	
3	17,000	30,000	33,180	58,500	.196	65.4	2.92	29.2	
4	16,000	28,200	33,370	58,800	.189	66.8	3.01	30.1	
1	12,000	26,400	22,060	48,600	.212	53.2	2.84	28.4	
2	11,000	24,300	22,230	49,000	.209	55.0	2.75	27.5	
3	12,000	25,800	22,550	48,400	.238	49.0	2.94	29.4	
4	12,000	26,400	22,100	48,700	.221	51.4	2.88	28.8	
1	.....	.....	13,340	29,250	.332	27.2	1.75	21.9	Broke at a flaw. These composition specimens were made up as follows: copper, 88%, zinc, 2%, tin, 10%. The same material was tried in the torsion tests.
2	.....	.....	14,470	30,910	.302	35.5	2.30	28.8	
3	.....	.....	13,650	29,780	.292	36.2	2.00	25.0	
4	.....	.....	13,910	30,970	.292	34.9	2.22	27.8	

Rope Tests.

This series of tests upon rope had for its object, first, to determine the relative holding power of various forms of knots; and second, to ascertain the average stretch of new rope under the application of a steadily increasing load. The tests of each kind were all made upon specimens taken from one coil. The length of specimen between fastenings was in all cases about 5 feet. The average strength of the rope used in calculating the efficiency of the knots was taken as the average of the breaking loads of a number of spliced specimens which gave away at the center. The knots used are shown by the accompanying cuts (Figures 7 to 12), and the stretches by the curves on the plot (Figure 6).

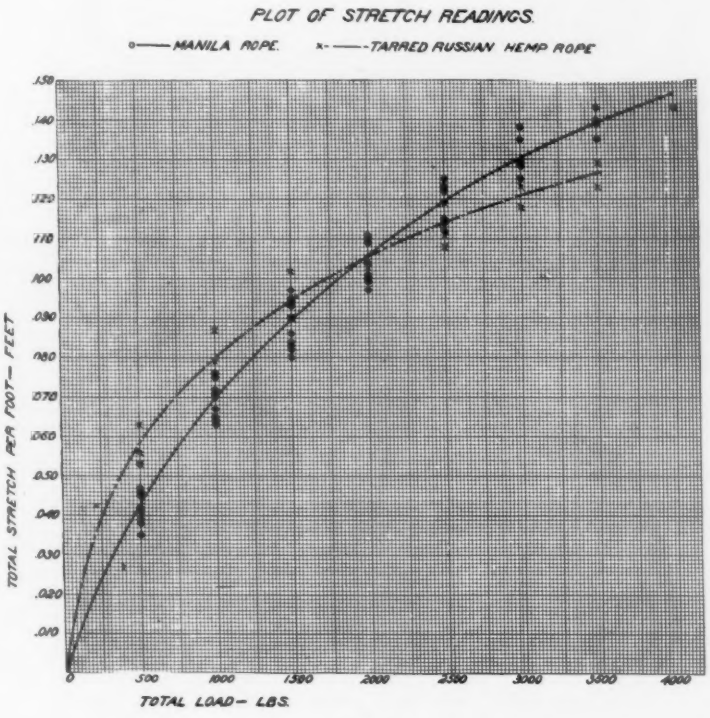


Fig. 6.

FIG. 7.
PLAIN SLIP KNOT.

FIG. 8.
FLEMISH LOOP.

FIG. 9.
TIMBER HITCH.

FIG. 10.
BOWLINE.

FIG. 11.
DOUBLE HALF HITCH.

FIG. 12.
EYE SPLICE.

TENSION TESTS ON 2½″ MANILA ROPE. (Three strands.)

Number of test.	Date, 1896–97.	Number of feet per pound.	Number of turns of one strand per foot.	Condition.	Location of Break.	Maximum load. (Lbs.)	Average strength. (Lbs.)	Efficiency of knot or splice. (Per cent.)	Method of Holding.
1	Nov. 11	5.0	5⅛	Splices wet. Center portion of rope dry.	At center.	5,390	5,420	100	Spliced eyes over iron eyes.
2	Nov. 11	5.0	5⅛		At center.	5,300			
3	Nov. 25	5.0	5⅛		At center.	5,540			
4	Dec. 1	5.0	5⅛		At center.	5,440			
5	Mar. 13	5.6	5⅜	Dry.	At lower knot.	4,430	4,280	79	Held at each end by a timber hitch knot over a 2″ pipe coupling.
6	Mar. 15	5.3	5⅜		At upper knot.	4,270			
7	Mar. 15	5.3	5⅜		At lower knot.	4,150			
8	Mar 17	5.9	5	Dry.	At upper knot.	3,820	3,750	69	Held at each end by a double half hitch knot over a 2″ pipe coupling.
9	Mar. 18	5.5	5⅛		At upper knot.	3,690			
10	Mar. 18	5.5	5⅛		At lower knot.	3,740			
11	Dec. 10	5.1	5	Dry.	At lower knot.	3,560	3,520	65	Held at each end by a slip knot over a 2″ pipe coupling.
12	Mar. 17	5.3	5⅛		At lower knot.	3,470			
13	Mar. 19	5.5	5⅛		At upper knot.	3,530			
14	Mar. 4	5.1	5⅛	Dry.	At lower knot.	2,950	2,880	53	Bowline knots over iron eyes.
15	Mar. 4	5.2	5⅛		At lower knot.	2,900			
16	Mar. 10	5.6	5		At lower knot.	2,800			
17	Mar. 10	5.5	5	Dry.	At lower knot.	2,430	2,500	46	Flemish loops over iron eyes.
18	Mar. 11	5.5	5⅛		At lower knot.	2,530			
19	Mar. 11	5.5	5⅛		At lower knot.	2,540			

TENSION TESTS ON 2½″ RUSSIAN HEMP ROPE. (Three strands.)

Number of test.	Date, 1896-97.	Number of feet per pound.	Number of turns of one strand per foot.	Condition.	Location of Break.	Maximum load. (Lbs.)	Average strength. (Lbs.)	Efficiency of knot or splice. (Per cent.)	Method of Holding.
1	Nov. 4, '95.*	...	5⅜	Splices wet. Center portion of rope dry.	At center.	7,020	6,580	100	Spliced eyes over iron eyes.
2	Nov. 22, '95.*	5	5⅜		At center.	6,880			
3	Mar. 20, '95.*	...	5		At center.	6,660			
4	Apr. 2, '95.*	5.5	5¼		At center.	6,290			
5	Apr. 5	5.5	5¼		At center.	6,030			
6	Mar. 31	5.3	5⅜	Dry.	At lower knot.	5,320	5,100	78	Timber hitches over 2″ pipe couplings.
7	Apr. 5	4.4	5¼		At lower knot.	5,030			
8	Apr. 5	4.4	5¼		At upper knot.	4,970			
9	Nov. 23	5.1	5¼	Dry.	At lower knot.	5,260	5,020	76	Slip knots over 2″ pipe couplings.
10	Dec. 7	5.0	5		At upper knot.	4,680			
11	Dec. 9	5.0	5		At lower knot.	5,130			
12	Nov. 13	5.0	5	Dry.	At upper knot.	4,190	3,920	60	Bowline knots over iron eyes.
13	Nov. 13	5.0	5		At lower knot.	3,870			
14	Nov. 25	5.0	5¼		At upper knot.	3,590			
15	Apr. 6	5.3	5¼		At lower knot.	4,010			
16	Nov. 13	5.0	5	Dry.	At upper knot.	3,230	3,550	54	Flemish loops over iron eyes.
17	Nov. 18	5.0	5		At lower knot.	4,030			
18	Nov. 23	5.1	5⅜		At upper knot.	3,700			
19	Mar. 31	5.2	5⅜		At upper knot.	3,250			

*These tests have been published before, and are quoted here for reference.

TENSION TESTS ON 2½″ TARRED RUSSIAN HEMP ROPE. (Three strands.)

Number of test.	Date, 1896–97.	Number of feet per pound.	Number of turns of one strand per foot.	Condition.	Location of Break.	Maximum load. (Lbs.)	Average strength. (Lbs.)	Efficiency of knot or splice. (Per cent.)	Method of Holding.
1	Nov. 6, '95.*	...	5½	Splices wet. Center portion of rope dry.	Near center.	5,250	5,250	100	Spliced eyes over iron eyes
2	Nov. 22, '95.*	4.3	6		Near center.	4,700			
3	Mar. 10, '96.*	4.5	5½		Near center.	5,790			
4	Apr. 12	4.4	6	Dry.	At upper knot.	3,780	3,790	72	Timber hitches over 2″ pipe couplings.
5	Apr. 12	4.4	6		At lower knot.	3,880			
6	Apr. 14	4.2	6		At upper knot.	3,700			
7	Dec. 2	4.0	5½	Dry.	At upper knot.	4,250	4,140	79	Slip knots over 2″ pipe couplings.
8	Dec. 3	5.1	6		At upper knot.	3,670			
9	Apr. 14	4.2	6		At upper knot.	4,490			
10	Dec. 2	4.3	6	Dry.	At upper knot.	3,260	2,980	57	Bowline knots over iron eyes.
11	Dec. 4	4.3	5½		At lower knot.	2,810			
12	Dec. 4	4.3	5½		At upper knot.	2,860			
13	Dec. 2	4.3	6	Dry.	At upper knot.	3,020	2,810	54	Flemish loops over iron eyes.
14	Dec. 2	4.3	6		At upper knot.	2,900			
15	Dec. 3	5.1	6		At lower knot.	2,510			

* These tests have been published before, and are quoted here for reference.

TENSION TESTS ON 2½″ TARRED AMERICAN HEMP ROPE. (Three strands.)

Number of test.	Date, 1896-97.	Number of feet per pound.	Number of turns of one strand per foot.	Condition.	Location of Break.	Maximum load. (Lbs.)	Average strength. (Lbs.)	Efficiency of knot or splice. (Per cent.)	Method of Holding.
1	Nov. 2	4.7	5½	Splices wet. Center portion of rope dry.	Near lower splice.	5,400	5,070	100	Spliced eyes over iron eyes.
2	Nov. 4	4.5	5½		Near lower splice.	5,080			
3	Nov. 4	4.4	5½		Near upper splice.	5,070			
4	Nov. 4	4.5	5½		Near upper splice.	4,980			
5	Apr. 27	4.6	5½		At center.	4,820			
6	Apr. 15	4.6	5½	Dry.	At upper knot.	4,490	4,250	84	Timber hitches over 2″ pipe couplings.
7	Apr. 15	4.7	5½		At lower knot.	3,920			
8	Apr. 28	4.7	5½		At lower knot.	4,340			
9	Nov. 9	4.5	5	Dry.	At lower knot.	4 490	4,560	90	Double half hitches over 2″ pipe couplings.
10	Nov. 9	4.5	5		At upper knot.	4,630			
11	Nov. 7	4.3	5⅛	Dry.	At lower knot.	4,760	4,650	92	Slip knots over 2″ pipe couplings.
12	Nov. 7	4.3	5⅛		At knot.	4,530			
13	Nov. 4	4.4	5	Dry.	At lower knot.	4,030	4,070	80	Bowline knots over iron eyes.
14	Nov. 6	...	5		At upper knot.	4,460			
15	Dec. 10	4 6	5⅛		At upper knot.	3,730			
16	Nov. 6	...	5	Dry.	At lower knot.	3,640	3,860	76	Flemish loops over iron eyes.
17	Nov. 7	4 3	5⅛		At upper knot.	3,950			
18	Dec. 15	4 8	..		At lower knot.	3,980			

TENSION TESTS ON NO. 10 JUTE TWINE. (Three strands.)

Number of test.	Date, 1896.	Number of feet per ounce.	Maximum load. (Lbs.)	Location of Break.	Method of Holding.
1	Oct. 24	88.6	38 5	3″ above lower clamp.	The cord was held by Proctor twine clamps in this series of tests.
2	Oct. 24	88.6	34 5	2″ below upper clamp.	
3	Oct. 28	79.5	34.5	At center.	
4	Oct. 28	76.7	33.5	Near lower clamp.	
5	Oct. 28	76.7	34.0	At center.	
6	Oct. 29	78.1	41.0	Near center.	
7	Oct. 30	78 1	35.0	Near lower clamp.	
8	Oct. 30	76.8	41.0	At center.	
9	Oct. 31	84.1	32.4	Near center.	
10	Oct. 31	82.9	37.8	At center.	
11	Oct. 31	84.1	34.3	Near lower clamp.	
12	Nov. 2	75.2	40.0	At center.	
13	Nov. 2	85.8	40.0	At center.	
14	Nov. 16	81.0	35.0	At center.	
15	Nov 16	81.0	43.5	At center.	
16	Nov. 16	76.6	37.6	At center.	

Note. — The length of specimen between clamps was about 18″. All these tests were made upon dry material.

TENSION TESTS ON NO. 48 JUTE TWINE. (Four strands.)

Number of test.	Date, 1896-97.	Number of feet per ounce.	Maximum load. (Lbs.)	Total stretch to fracture. (Per cent.)	Location of Break.	Method of Holding.
1	Nov. 26	29.8	102 6	2.4	4″ below upper clamp.	The cord was held by Proctor twine clamps in this series of tests.
2	Nov. 25	28.8	124.0	2.7	4″ above lower clamp.	
3	Dec. 2	31.4	97.0	2.8	In lower clamp.	
4	Dec. 2	27.2	97.0	2.5	Near middle.	
5	Dec. 2	27.2	96.0	2.7	At lower clamp.	
6	Dec. 7	29 8	101.0	3.7	Near center.	
7	Dec. 8	31.2	103.5	2.5	Near center.	
8	Dec. 8	31.2	99.5	2.6	Near center.	
9	Mar. 9	27.6	91.0	...	At center.	
10	Mar. 9	32.8	118.3	...	At center.	
11	Mar. 11	32.7	103.8	...	At upper clamp.	
12	Mar. 11	25.7	95.0	...	Near upper clamp.	
13	Mar. 18	29.7	98.5	...	2″ below upper clamp.	

Note. — The stretch was measured in a gauged length of 8″ or 10″. The length of specimen between clamps was about 18″. These tests were made upon dry material.

TENSION TESTS ON NO. 16 FLAX BOOT THREAD. (Six strands.)

Number of test.	Date, 1896.	Number of feet per ounce.	Maximum load. (Lbs.)	Location of Break.	Method of Holding.
1	Nov. 16	140.4	49.0	At lower clamp.	The cord was held by Proctor twine clamps in this series of tests.
2	Nov. 16	140.4	43.3	4″ above lower clamp.	
3	Nov. 16	135.2	45.7	At center.	
4	Nov. 17	136.8	48.0	Near center.	
5	Nov. 17	128.7	43.6	Near center.	
6	Nov. 17	136.8	40.0	Near lower clamp.	
7	Nov. 17	136.8	39.3	At center.	
8	Nov. 17	136.8	40.1	At lower clamp.	
9	Nov. 17	136.8	40.0	Near lower clamp.	
10	Nov. 17	136.8	40.5	Near center.	
11	Nov. 17	125.0	44.0	At lower clamp.	
12	Nov. 19	136.7	40.3	At center.	
13	Nov. 19	136.7	40.0	At center.	
14	Nov. 19	141.1	46.2	At center.	
15	Nov. 19	118.2	39.6	At center.	
16	Nov. 19	136.7	39.7	At center.	
17	Nov. 19	136.7	38.7	At center.	
18	Nov. 19	118.2	42.7	At center.	
19	Nov. 25	133.6	37.9	Near center.	
20	Nov. 30	134.3	42.0	Just below upper clamp.	
21	Nov. 30	134.6	47.0	Near center.	
22	Nov. 30	128.7	45.3	Near center.	
23	Nov. 30	128.7	40.0	At center.	
24	Nov. 30	134.6	44.0	Near center.	

Note. — The length of specimen between clamps was about 28″. These tests were made upon dry material.

TENSION TESTS ON NO. 3½ BRAIDED CURTAIN CORD.

Number of test.	Date, 1897.	Number of feet per ounce.	Maximum load. (Lbs.)	Location of Break.	Method of Holding.
1	Feb. 15	10.7	109.0	2″ below upper clamp.	The cord was held by Proctor twine clamps in this series of tests.
2	Feb. 26	10.8	107.5	Near lower clamp.	
3	Feb. 26	....	107.5	Near lower clamp.	
4	Mar. 1	10.9	110 0	Near center.	
5	Mar. 3	9.8	114.9	At center.	
6	Mar. 4	10.8	99.0	Just below upper clamp.	
7	Mar. 5	10.9	116.9	At center.	
8	Mar. 5	10.7	105.6	At upper clamp.	
9	Mar. 9	....	105.0	At center.	
10	Mar. 9	10.9	103.4	At center.	
11	Mar. 11	10.7	108 3	At center.	
12	Mar. 11	10.7	102.5	Near center.	
13	Mar. 11	11.0	98.7	Near lower clamp.	
14	Mar. 18	10.7	108.5	In lower clamp.	
15	Mar. 18	10.3	112.2	Near lower clamp.	

Notes. — This cord was made of white braided cotton. It was composed of nine strands, each of four threads, braided over a core of four threads.

The length between clamps was about 18″.

These tests were made upon dry material.

TENSION TESTS ON No. 8 SAMSON BRAIDED SASH CORD.

Number of test.	Date, 1897.	Number of feet per ounce.	Maximum load. (Lbs.)	Location of Break.	Method of Holding.
1	Feb. 19	2.32	284.0	4″ below upper clamp.	In tests No. 1 to 13 inclusive the cord was held by Proctor twine clamps.
2	Feb. 26	2.28	280.0	Near center.	
3	Mar. 1	2.33	282.0	Near center.	
4	Mar. 3	2.30	298.0	At center.	
5	Mar. 4	2.32	282.0	Just below upper clamp.	
6	Mar. 5	2.35	280.0	At center.	
7	Mar. 5	2.33	299.5	In upper clamp.	
8	Mar. 11	2.35	292.0	At center.	
9	Mar. 18	2.25	303.5	At center.	
10	Mar. 20	2.32	304.0	Near center.	
11	Mar. 25	2.33	286.5	At center.	
12	Mar. 25	2.33	291.0	Near upper clamp.	
13	Mar. 29	2.32	285.8	At upper clamp.	
14	Mar. 29	2.31	291.0	Near upper knot.	Timber hitch knots.
15	Mar. 29	2.32	281.0	In upper knot.	Slip knots.
16	Mar. 29	2.32	271.0	In upper knot.	Bowline knots.
17	Mar. 29	2.34	229.0	In upper knot.	Flemish loop knots.

Notes. — This cord was made of drab braided cotton. It was composed of twelve strands, each of nine threads, braided over a core of ten threads.

The knot holdings were made over Proctor clamps, which were 2½″ in diameter. The last four tests may be compared with similar ones upon rope, to show the relative efficiency of the knots used.

The length of cord between clamps was 18″.

All the tests were made upon dry material.

TENSION TESTS ON No. 9 SAMSON BRAIDED SASH CORD.

Number of test.	Date, 1897.	Number of feet per ounce.	Method of Holding	Maximum load. (Lbs.)	Average strength. (Lbs.)	Efficiency of knot or holding, as compared with total strength of specimen. (Per cent.)	Location of Break.
1	Apr. 9	2.21	Proctor clamps.	351			At center.
2	Apr. 13	2.03	Proctor clamps.	344			At center.
3	Apr. 17	2.20	Proctor clamps.	359			Near lower clamp.
4	Apr. 27	2.23	Timber hitches.	356	350	100	Near center.
5	Apr. 27	2.28	Timber hitches.	350			At center.
6	Apr. 27	2.14	Timber hitches.	348			Near lower knot.
7	Apr. 28	2.26	Timber hitches.	342			Near center.
8	Apr. 13	2.22	Bowline knots.	300			Lower knot.
9	Apr. 13	2.23	Bowline knots.	295			Lower knot.
10	Apr. 17	2.11	Bowline knots.	320	309	88	Lower knot.
11	Apr. 27	2.23	Bowline knots.	320			Lower knot.
12	Apr. 9	2.23	Flemish loop knots.	276			Lower knot.
13	Apr. 17	2.02	Flemish loop knots.	278	280	80	Lower knot.
14	Apr. 27	2.28	Flemish loop knots.	285			Lower knot.
15	Apr. 27	2.22	Timber hitches with square	291			In square knot.
16	Apr. 27	....	knot at center of speci-	290	290	83	In square knot.
17	Apr. 27	2.29	men.	290			In square knot.
18	Apr. 27	2.21	Timber hitches and open-	258			At open-hand knot.
19	Apr. 27	2.22	hand knot at center of	259	268	77	At open-hand knot.
20	Apr. 28	2.43	specimen.	289			At open-hand knot.

Notes. — The length of specimen between clamps was 18″.

This cord was made of drab braided cotton, and consisted of fifteen strands of eight threads each, braided over a core of ten threads.

The knots were tied over a Proctor clamp which was 2¼″ in diameter.

These tests were made upon dry material.

TENSION TESTS ON $\frac{5}{16}$″ FABER LINEN SASH CORD.

Number of test.	Date, 1897.	Number of feet per ounce.	Maximum load. (Lbs.)	Location of Break.	Method of Holding.
1	Feb. 19	1.70	671	2″ above lower clamp.	The cord was held by Proctor clamps in this series of tests.
2	Feb. 26	1.70	582	In upper clamp.	
3	Mar. 1	1.71	625	In upper clamp.	
4	Mar. 3	1.71	639	Near lower clamp.	
5	Mar. 4	....	606	In upper clamp.	
6	Mar. 5	1.71	685	In upper clamp.	
7	Mar. 10	1.68	690	In upper clamp.	
8	Mar. 13	1.72	660	At lower clamp.	The cord was dry in this series of tests.
9	Mar. 25	1.73	713	At center.	
10	Mar. 26	1.69	613	At lower clamp.	
11	Mar. 29	1.91	687	At center.	

Notes. — The length of specimen between clamps was 18″.

This cord was made of twisted linen, and consisted of four strands of three threads each, twisted around a core of six threads.

The core was of Russian hemp.

The number of twists of one strand was about twelve per foot.

The Proctor clamp did not prove as good a holding for this as for the smaller cord, since most of the specimens broke in or near the clamp.

TENSION TESTS ON ⅜″ BELT LACINGS.

Number of test.	Date, 1896–97.	Weight per yard. (Ounces.)	Gauged length. (Ins.)	Maximum load. (Lbs.)	Ultimate extension in gauged length. (Ins.)	Ultimate extension in gauged length. (Per cent.)
1	Nov. 20	.78	8.00	224	2.52	31 5
2	Nov. 21	.49	8.00	177	2 18	27.3
3	Nov. 21	1.23	8.00	245	2.10	26.3
4	Nov. 23	.73	8.00	207	1.58	19.8
5	Nov. 23	.67	8.00	215	3.00	37.5
6	Nov. 23	.50	8.00	203	1.78	22.2
7	Nov. 23	.71	8 00	221	2.25	28.1
8	D·c. 15	.53	8.00	185	1.25	15.6
9	Dec. 15	.77	8.00	220	1.40	17.5
10	Mar. 30	.69	....	205	....	....
11	Mar. 30	.72	....	274	....	....
12	Mar. 31	.61	....	237	....	....
13	Mar. 31	.74	....	210	....	....
14	Apr. 7	.47	....	162	....	....

NOTE. — The lacings were held by Proctor twine clamps. The material was ordinary "split raw hide."

TENSION TESTS ON LEATHER BELTS.

Number of test.	Date, 1897.	Dimensions of cross section. (Ins.)	Area of cross section. (Sq. ins.)	Maximum load. (Lbs.)	Maximum load. (Lbs. per sq. in.)	Gauged length. (Ins.)	Ultimate extension in gauged length. (Ins.)	Ultimate extension in gauged length. (Per cent.)	KIND OF BELT.
1	Mar. 17	.32 x 2.96	.947	6,440	6,800	6.00	1.58	26.3	Indian tanned leather.
2	Mar. 17	.34 x 2.50	.850	3,400	4,000	2.00	.31	15.5	Schieren electric.
3	Mar. 17	.34 x 2.53	.860	3,250	3,780	....	....	....	Schieren electric.
4	Mar. 17	.34 x 2.48	.843	3,700	4,390	2.00	.31	15.5	Schieren electric.
5	Mar. 17	.34 x 2.42	.823	4,050	4,920	2.00	.31	15.5	Schieren electric.

TRANSVERSE STRENGTH OF SPRUCE BEAMS.

Load applied at middle of span.

Number of test.	Width and depth. (Ins.)	Distance between supports. (Feet.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Deflection for difference of loads used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)	Breaking load. (Lbs.)	Weight of beam. (Lbs.)	Modulus of rupture. (Lbs. per sq. in.)	Maximum intensity of longitudinal shear. (Lbs. per sq. in.)	Manner of Breaking.	Remarks.
536	3⅞ x 12	14	500–3,500	.4306	1,233,000	10,005	150	4,550	164	Tension.	
537	4 x 12	13	500–4,500	.4865	1,129,000	10,475	150	4,290	166	Tension.	
538	3⅞ x 12	14	500–5,000	.6604	1,247,000	10,615	140	4,990	179	Tension.	
539	3⅞ x 11⅞	14	500–2,000	.4082	691,000	3,315	155	1,610	58	Tension.	Very poor quality.
540	4 x 11⅞	14	500–3,500	.4661	1,139 000	8,565	150	3,860	138	Tension.	
541	3⅞ x 12	17	500–3,000	.6768	1,171,000	6,165	200	3,440	103	Tension and crushing.	
543	3⅞ x 12	8	500–6,500	.2125	964,000	17,815	90	4,760	298	Longitudinal shear.	Part of beam No. 541.
544	3⅞ x 11⅞	13	500–3,500	.5106	859,000	4,440	160	1,940	75	Tension.	Poor quality.
545	3⅞ x 12	14	500–5,000	.6107	1,305,000	11,815	150	5,370	193	Longitudinal shear.	
546	4⅛ x 12	13	500–3,500	.3122	1,279,000	9,915	150	3,940	153	Longitudinal shear.	
572	3⅞ x 12	12	500–4,500	.4165	1,071,000	10,525	125	4,100	172	Longitudinal shear.	
573	3⅞ x 11½	10½	500–6,500	.3503	1,457,000	19,325	115	7,150	327	Longitudinal shear and tension.	Old, well seasoned. Used as plank in laboratory.
574	2 x 11½	11	500–4,500	.5244	1,471,000	9,960	60	7,480	327	Tension.	
575	3⅞ x 12	11	500–6,500	.3715	1,426,000	13,740	160	4,900	225	Tension.	
576	3⅞ x 12	11	1,000–7,000	.3987	1,336.000	13,850	150	5,110	233	Tension.	
577	4 x 12	11	1,000–7,000	.4650	1,073,000	13,315	125	4,600	210	Tension.	
579	3⅞ x 12	11	500–4,500	.2910	1,180,000	13,750	130	4,900	224	Longitudinal shear and tension.	

TRANSVERSE STRENGTH OF SPRUCE BEAMS.

Load equally distributed over two points equally spaced between supports dividing span into thirds.

Number of test.	Width and depth. (Ins.)	Distance between supports. (Feet.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Deflection for difference of loads used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)	Breaking load. (Lbs.)	Weight of beam. (Lbs.)	Modulus of rupture. (Lbs. per sq. in.)	Maximum intensity of longitudinal shear. (Lbs. per sq. in.)	Manner of Breaking.	Remarks.
547	$3\frac{3}{8}$ x 12	14	500–6,500	.7162	1,305,000	12,210	155	3,840	206	Tension.	
548	$3\frac{3}{8}$ x $11\frac{7}{8}$	13	500–6,500	.7329	1,020,000	14,130	130	4,060	232	Tension.	
549	$3\frac{3}{8}$ x 12	12	500–4,500	.4209	882,000	12,125	140	3,160	198	Tension.	
550	$3\frac{3}{8}$ x $12\frac{1}{8}$	12	500–4,500	.3752	960,000	12,280	140	3,130	198	Tension.	
551	4 x 12	12	500–6,500	.4227	1,276,000	19,455	130	4,890	306	Tension.	
552	$3\frac{3}{8}$ x $12\frac{1}{8}$	12	500–6,500	.5598	965,000	12,080	140	3,080	195	Tension.	
553	4 x $11\frac{7}{8}$	14	500–6,500	.6944	1,302,000	15,280	165	4,590	244	Tension.	
554	4 x 12	12	500–4,500	.3592	1,001,000	11,780	140	2,970	186	Longitudinal shear.	
555	$3\frac{7}{8}$ x 12	12	1,500–6,500	.4493	1,086,000	15,605	125	4,260	267	Tension.	Broke at knot.
557	4 x $11\frac{3}{4}$	12	500–3,500	.2496	1,166,000	12,675	130	2,920	204	Longitudinal shear and tension.	In this beam the load was applied at two points $2\frac{1}{2}$ feet each side of center.

TRANSVERSE STRENGTH OF SPRUCE BEAMS.

Load equally distributed over four points equally spaced between supports dividing span into fifths.

Number of test.	Width and depth. (Ins.)	Distance between supports. (Feet.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Deflection for difference of loads used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)	Breaking load. (Lbs.)	Weight of beam. (Lbs.)	Modulus of rupture. (Lbs. per sq. in.)	Maximum intensity of longitudinal shear. (Lbs. per sq. in.)	Manner of Breaking.	Remarks.
556	3 7/8 x 11 13/16	12	500–6,500	.3483	1,551,000	22,930	125	5,640	388	Tension.	
558	3 7/8 x 11 13/16	12	500–6,500	.3717	1,497,000	27,240	120	6,840	466	Tension.	
559	3 7/8 x 11 13/16	14	500–6,500	.5940	1,442,000	17,375	130	5,000	295	Longitudinal shear.	
560	4 12	12	500–6,500	.3005	1,631,000	34,125	130	7,700	535	Longitudinal shear.	
561	4 x 12	11	500–6,500	.2826	1,336,000	20,450	140	4,240	322	Longitudinal shear and tension.	
562	3 7/8 x 11 13/16	12	500–6,500	.4833	1,115,000	14,125	125	3,450	235	Longitudinal shear and tension.	Poor quality.
563	4 1/16 x 12	11 1/2	500–6,500	.5154	812,000	9,340	90	2,260	149	Tension.	Very poor quality.
564	3 7/8 x 11 13/16	11	500–6,500	.2951	1,557,000	21,800	115	5,380	399	Longitudinal shear.	
565	3 7/8 x 12	12 1/2	500–6,500	.5727	1,032,000	14,145	130	3,560	238	Tension.	
566	3 7/8 x 12	12	500–6,500	.4035	1,254,000	23,085	135	5,390	374	Tension.	
567	3 7/8 x 12	11	500–6,500	.2841	1,371,000	28,975	130	6,190	469	Tension.	
568	4 x 12	12	500–6,500	.5172	947,000	13,860	140	3,900	219	Tension.	
569	4 x 12	12	500–6,500	.3543	1,383,000	19,650	140	4,450	309	Tension.	
570	4 x 12	11	500–4,500	.3223	780,000	7,450	120	1,560	118	Tension.	Very poor quality.
571	3 1/2 x 12	12	500–6,500	.3910	1,432,000	20,550	120	5,310	369	Tension.	

TRANSVERSE STRENGTH OF YELLOW PINE.

Load applied at middle of span.

Number of test.	Width and depth. (Ins.)	Distance between supports. (Feet.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Deflection for difference of loads used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)	Breaking load. (Lbs.)	Weight of beam. (Lbs.)	Modulus of rupture. (Lbs. per sq. in.)	Maximum intensity of longitudinal shear. (Lbs. per sq. in.)	Manner of Breaking.	Remarks.
503	8 x 10	19	500–4,000	.5000	2,300,000	26.120	...	8,890	244	Tension crushing and shearing.	
542	7⅞ x 10	10	500–9,500	.2426	2,035,000	42,795	250	9,810	410	Longitudinal shear.	

TRANSVERSE STRENGTH OF COMPOSITION BARS.

Load applied at middle of span.

Number of test.	Width and depth. (Ins.)	Distance between supports. (Feet.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Deflection for difference of loads used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)	Breaking load. (Lbs.)	Weight of beam. (Lbs.)	Modulus of rupture. (Lbs. per sq. in.)	Remarks.
535a	1.45 x 1.45	2.5	50– 550	.0633	12,100,000	.....	23	.....	85% copper, 7% zinc, 8% tin.
535b	1.43 x 1.45	2.5	100– 600	.0680	11,400,000	1,380	22	21,000	65% copper, 35% zinc.
535c	1.46 x 1.46	2.5	100–1,000	.1081	12,300,000	2,120	23	31,300	85% copper, 7% zinc, 8% tin.

Note. — Tensile tests of this composition are given in Vol. V, pages 202, 203.

NEAT CEMENT. (Tension.)

Date of Test.	Kind of Cement.	Brand.	Per cent. of water used in mixing.	Time of set. (Days.)	Breaking strength.
Nov. 16, 1896 . . .	Rosendale.	Hoffman.	30	7	99
Nov. 16, 1896 . . .	Rosendale.	Hoffman.	30	7	119
Nov. 16, 1896 . . .	Rosendale.	Hoffman.	30	7	128
Nov. 16, 1896 . . .	Rosendale.	Hoffman.	30	7	132
Nov. 17, 1896 . . .	Rosendale.	Hoffman.	30	7	93
Nov. 17, 1896 . . .	Rosendale.	Hoffman.	30	7	102
Nov. 18, 1896 . . .	Rosendale.	Hoffman.	30	7	92
Nov. 18, 1896 . . .	Rosendale.	Hoffman.	30	7	93
Nov. 18, 1896 . . .	Rosendale.	Hoffman.	30	7	95
Nov. 18, 1896 . . .	Rosendale.	Hoffman.	30	7	103
Nov. 30, 1896 . . .	Rosendale.	Hoffman.	30	7	95
Dec. 1, 1896 . . .	Rosendale.	Hoffman.	30	7	101
Dec. 1, 1896 . . .	Rosendale.	Hoffman.	30	7	109
Nov. 13, 1896 . . .	Portland.	B. S. & Co.	25	383	780
Nov. 13, 1896 . . .	Portland.	B. S. & Co.	25	383	780
Nov. 13, 1896 . . .	Portland.	B. S. & Co.	25	383	864
Nov. 13, 1896 . . .	Portland.	B. S. & Co.	25	384	832
Nov. 13, 1896 . . .	Portland.	B. S. & Co.	25	384	855
Nov. 13, 1896 . . .	Portland.	B. S. & Co.	25	384	856
Nov. 13, 1896 . . .	Portland.	B. S. & Co.	25	384	858
Dec. 2, 1896 . . .	Portland.	B. S. & Co.	25	411	788
Dec. 2, 1896 . . .	Portland.	B. S. & Co.	25	411	814
Dec. 2, 1896 . . .	Portland.	B. S. & Co.	25	411	874
Dec. 8, 1896 . . .	Portland.	B. S. & Co.	25	417	816
Dec. 9, 1896 . . .	Portland.	B. S. & Co.	25	417	832
Dec. 8, 1896 . . .	Portland.	B. S. & Co.	25	418	827
Nov. 4, 1896 . . .	Portland.	Anchor.	24	5	406
Nov. 4, 1896 . . .	Portland.	Anchor.	24	5	411
Nov. 4, 1896 . . .	Portland.	Anchor.	24	5	408
Nov. 4, 1896 . . .	Portland.	Anchor.	24	5	440
Oct. 28, 1896 . . .	Portland.	Anchor.	25	7	482
Oct. 29, 1896 . . .	Portland.	Anchor.	23	7	450
Oct. 30, 1896 . . .	Portland.	Anchor.	24	7	474
Oct. 30, 1896 . . .	Portland.	Anchor.	24	7	489
Nov. 2, 1896 . . .	Portland.	Anchor.	24	7	500
Nov. 4, 1896 . . .	Portland.	Anchor.	24	7	540
Nov. 13, 1896 . . .	Portland.	Anchor.	24	7	460
Nov. 13, 1896 . . .	Portland.	Anchor.	24	7	465
Mar. 8, 1897 . . .	Portland.	Anchor.	24	7	462
Mar. 8, 1897 . . .	Portland.	Anchor.	24	7	472
Mar. 8, 1897 . . .	Portland.	Anchor.	24	7	480
Mar, 8, 1897 . . .	Portland.	Anchor.	24	7	488
Mar. 4, 1897 . . .	Portland.	Anchor.	24	7	474
Mar. 4, 1897 . . .	Portland.	Anchor.	24	7	510

NEAT CEMENT. (Tension.) — *Concluded.*

Date of Test.	Kind of Cement.	Brand.	Per cent. of water used in mixing.	Time of set. (Days.)	Breaking strength.
Mar. 8, 1897 . . .	Portland.	Anchor.	24	7	520
Mar. 8, 1897 . . .	Portland.	Anchor.	24	7	536
Mar. 8, 1897 . . .	Portland.	Anchor.	24	7	542
Mar. 8, 1897 . . .	Portland.	Anchor.	24	7	578
Mar. 8, 1897 . . .	Portland.	Anchor.	24	7	607
Mar. 8, 1897 . . .	Portland.	Anchor.	24	7	502
Mar. 9, 1897 . . .	Portland.	Anchor.	24	7	495
Mar. 9, 1897 . . .	Portland.	Anchor.	24	7	571
Mar. 9, 1897 . . .	Portland.	Anchor.	24	7	580
Mar. 10, 1897 . . .	Portland.	Anchor.	24	7	482
Mar. 10, 1897 . . .	Portland.	Anchor.	24	7	484
Mar. 10, 1897 . . .	Portland.	Anchor.	24	7	550
Mar. 10, 1897 . . .	Portland.	Anchor.	24	7	492
Mar. 10, 1897 . . .	Portland.	Anchor.	24	7	566
Mar. 11, 1897 . . .	Portland.	Anchor.	24	7	484
Mar. 29, 1897 . . .	Portland.	Anchor.	24	27	642
Mar. 29, 1897 . . .	Portland.	Anchor.	24	27	680
Mar. 29, 1897 . . .	Portland.	Anchor.	24	27	680
Apr. 8, 1897 . . .	Portland.	Anchor.	24	35	660
Apr. 8, 1897 . . .	Portland.	Anchor.	24	35	728
Apr. 15, 1897 . . .	Portland.	Anchor.	24	42	686
Apr. 13, 1897 . . .	Portland.	Atlas.	18	1	191
Apr. 13, 1897 . . .	Portland.	Atlas.	18	1	192
Apr. 15, 1897 . . .	Portland.	Atlas.	18	3	308
Apr. 15, 1897 . . .	Portland.	Atlas.	18	3	338
Mar. 24, 1897 . . .	Portland.	Atlas.	18	7	530
Mar. 24, 1897 . . .	Portland.	Atlas.	18	7	552
Mar. 24, 1897 . . .	Portland.	Atlas.	18	7	530
Mar. 25, 1897 . . .	Portland.	Atlas.	18	7	540
Mar. 25, 1897 . . .	Portland.	Atlas.	18	7	548
Mar. 25, 1897 . . .	Portland.	Atlas.	18	7	583
Mar. 25, 1897 . . .	Portland.	Atlas.	18	7	667
Mar. 29, 1897 . . .	Portland.	Atlas.	18	7	560
Apr. 22, 1897 . . .	Portland.	Atlas.	15	7	565
Apr. 22, 1897 . . .	Portland.	Atlas.	15	7	710
Apr. 22, 1897 . . .	Portland.	Atlas.	18	7	768
Apr. 22, 1897 . . .	Portland.	Atlas.	18	7	815
Apr. 22, 1897 . . .	Portland.	Atlas.	18	7	756
Apr. 22, 1897 . . .	Portland.	Atlas.	18	7	785
Apr. 28, 1897 . . .	Portland.	Atlas.	18	15	960
Apr. 12, 1897 . . .	Portland.	Atlas.	18	27	800
Apr. 12, 1897 . . .	Portland.	Atlas.	18	27	800
Apr. 12, 1897 . . .	Portland.	Atlas.	18	27	840

SAND TESTS. (Tension.)

Date of Test.	Kind of Cement.	Brand.	Parts sand to one part cement.	Per cent. of water used in mixing.	Number of days set.	Breaking strength.
Oct. 28, 1896 . . .	Portland.	Anchor.	2	8	7	190
Oct. 29, 1896 . . .	Portland.	Anchor.	2	10	7	153
Oct. 29, 1896 . . .	Portland.	Anchor.	2	10	7	168
Oct. 30, 1896 . . .	Portland.	Anchor.	2	10	7	159
Oct. 30, 1896 . . .	Portland.	Anchor.	2	10	7	188
Oct. 30, 1896 . . .	Portland.	Anchor.	2	10	7	214
Nov. 2, 1896 . . .	Portland.	Anchor.	2	8	7	167
Nov. 4, 1896 . . .	Portland.	Anchor.	2	8	7	175
Nov. 4, 1896 . . .	Portland.	Anchor.	2	8	7	182

SAND TESTS. (Compression.)

Date of Test.	Kind of Cement.	Brand.	Parts sand to one part cement.	Per cent. of water used in mixing.	Number of days set.	Breaking strength.
Oct. 28, 1896 . . .	Portland.	Anchor.	2	8	7	9,600
Oct. 28, 1896 . . .	Portland.	Anchor.	2	8	7	12,100
Oct. 29, 1896 . . .	Portland.	Anchor.	2	10	7	9,700
Oct. 30, 1896 . . .	Portland.	Anchor.	2	10	7	9,470
Oct. 30, 1896 . . .	Portland.	Anchor.	2	10	7	9,570
Oct. 30, 1896 . . .	Portland.	Anchor.	2	10	7	9,840
Nov. 2, 1896 . . .	Portland.	Anchor.	2	8	7	9,150
Nov. 4, 1896 . . .	Portland.	Anchor.	2	10	5	7,940
Nov. 4. 1896 . . .	Portland.	Anchor.	2	10	5	8,440

NOTES. — Sand used in these tests was common building sand.
These tests were on 2-inch cubes.

NEAT CEMENT. (Compression.)

Date of Test.	Kind of Cement.	Brand.	Per cent. of water used in mixing.	Time of set. (Days.)	Breaking strength.
Nov. 16, 1896	Rosendale.	Hoffman.	30	7	2,600
Nov. 16, 1896	Rosendale.	Hoffman.	30	7	2,755
Nov. 16, 1896	Rosendale.	Hoffman.	30	7	2,900
Nov. 16, 1896	Rosendale.	Hoffman.	30	7	2,970
Nov. 17, 1896	Rosendale.	Hoffman.	30	7	2,280
Nov. 17, 1896	Rosendale.	Hoffman.	30	7	2,440
Nov. 18, 1896	Rosendale.	Hoffman.	30	7	2,490
Nov. 18, 1896	Rosendale.	Hoffman.	30	7	2,520
Nov. 18, 1896	Rosendale.	Hoffman.	30	7	2,590
Nov. 30, 1896	Rosendale.	Hoffman.	30	7	2,300
Nov. 30, 1896	Rosendale.	Hoffman.	30	7	2,580
Nov. 30. 1896	Rosendale.	Hoffman.	30	7	2,700
Nov. 30, 1896	Rosendale.	Hoffman.	30	7	3,010
Dec. 1, 1896	Rosendale.	Hoffman.	30	7	2,230
Dec. 1, 1896	Rosendale.	Hoffman.	30	7	2,320
Dec. 1, 1896	Rosendale.	Hoffman.	30	7	2,390
Dec. 1, 1896	Rosendale.	Hoffman.	30	7	2,450
Dec. 1, 1896	Rosendale.	Hoffman.	30	7	2,580
Dec. 1, 1896	Rosendale.	Hoffman.	30	7	2,630
Nov. 4, 1896	Portland.	Anchor.	24	5	11,830
Nov. 4, 1896	Portland.	Anchor.	24	5	12,000
Nov. 4, 1896	Portland.	Anchor.	24	5	13,320
Nov. 4, 1896	Portland.	Anchor.	24	5	13,840
Oct. 28, 1896	Portland.	Anchor.	25	7	14,700
Oct. 28, 1896	Portland.	Anchor.	25	7	14,780
Oct. 28, 1896	Portland.	Anchor.	25	7	15,330
Oct. 28, 1896	Portland.	Anchor.	25	7	15,330
Oct. 29, 1896	Portland.	Anchor.	23	7	15,040
Oct. 29, 1896	Portland.	Anchor.	23	7	15,480
Oct. 29, 1896	Portland.	Anchor.	23	7	17,030
Nov. 2, 1896	Portland.	Anchor.	24	7	14,150
Nov. 2, 1896	Portland.	Anchor.	24	7	14,250
Nov. 2, 1896	Portland.	Anchor.	24	7	15,800
Nov. 4, 1896	Portland.	Anchor.	24	7	14,400
Nov. 4, 1896	Portland.	Anchor.	24	7	15,200
Nov. 4, 1896	Portland.	Anchor.	24	7	16,350
Nov. 4, 1896	Portland.	Anchor.	24	7	17,150
Nov. 6, 1896	Portland.	Anchor.	24	7	14,300
Nov. 6, 1896	Portland.	Anchor.	24	7	14,890
Mar. 8, 1897	Portland.	Anchor.	24	7	15,470
Mar. 8, 1897	Portland.	Anchor.	24	7	15,540
Mar. 4, 1897	Portland.	Anchor.	24	7	15,000
Mar. 4, 1897	Portland.	Anchor.	24	7	15,190
Mar. 4, 1897	Portland.	Anchor.	24	7	15,450
Mar. 4, 1897	Portland.	Anchor.	24	7	15,830
Mar. 4, 1897	Portland.	Anchor.	24	7	15,900
Mar. 4, 1897	Portland.	Anchor.	24	7	15,980
Mar. 8, 1897	Portland.	Anchor.	24	7	15,700
Mar. 10, 1897	Portland.	Anchor.	24	7	14,750
Mar. 10, 1897	Portland.	Anchor.	24	7	15,400
Mar. 10, 1897	Portland.	Anchor.	24	7	14,430
Mar. 10, 1897	Portland.	Anchor.	24	7	14,550
Mar. 10, 1897	Portland.	Anchor.	24	7	15,020
Mar. 29, 1897	Portland.	Anchor.	24	27	19,160
Mar. 29, 1897	Portland.	Anchor.	24	27	20,000
Apr. 8, 1897	Portland.	Anchor.	24	35	19,975
Apr. 15, 1897	Portland.	Anchor.	24	49	24,475
Apr. 15, 1897	Portland.	Anchor.	24	49	25,500
Apr. 13, 1897	Portland.	Atlas.	18	1	3,500
Apr. 13, 1897	Portland.	Atlas.	18	1	3,950
Apr. 13, 1897	Portland.	Atlas.	18	1	4,100
Mar. 24, 1897	Portland.	Atlas.	20	7	14,760
Mar. 24, 1897	Portland.	Atlas.	18	7	21,330
Mar. 24, 1897	Portland.	Atlas.	18	7	21,600
Mar. 24, 1897	Portland.	Atlas.	18	7	22,900
Mar. 24, 1897	Portland.	Atlas.	18	7	23,560
Apr. 28, 1897	Portland.	Atlas.	18	15	29,600
Apr. 28, 1897	Portland.	Atlas.	18	15	31,060

NOTE. — These tests were all on 2-inch cubes.

ON ODORS AND TASTES OF SURFACE WATERS, WITH SPECIAL REFERENCE TO ANABÆNA, A MICROSCOPICAL ORGANISM FOUND IN CERTAIN WATER SUPPLIES OF MASSACHUSETTS.

By D. D. JACKSON, Assistant Biologist, and J. W. ELLMS, Assistant Chemist, of the Massachusetts State Board of Health.

It is commonly believed by those who have not investigated the subject, that disagreeable odors and tastes in drinking waters are due to the decomposition of organic matter, and are either dangerous or indicative of danger to the public health. Biological investigations already published have sufficed to show that this is not always the case.[1]

There is no longer any doubt that in many cases — perhaps most cases — the peculiar odors and tastes of surface waters are due, not to decay, but to the presence of living or undecomposed microscopical organisms, either animal or vegetable, in the water affected. This conclusion rests upon various facts, one of which is that in many instances the intensity of the odor keeps pace with the growth of the organisms, while bacteriological examinations prove the absence of conditions of organic putrefaction or decay. The fact that certain microscopical organisms possess peculiar and characteristic odors during life is not surprising, when we consider how characteristic are the odors of some of the larger plants and animals with which we are all familiar.

Several of the microscopic forms[2] have been found to contain oily products in considerable quantities at a certain stage of their growth, and in the case of Uroglena an oil has been shown to be the cause of the disagreeable odor and taste which usually accompany the or-

[1] "Odors in Drinking Waters." Report Mass. State Board of Health, 1892, p. 353.

[2] On Uroglena. Report Mass. S. B. H., 1891, p. 645. — Synura. 18th Annual Report Boston Water Works, 1893.

ganism. By a series of experiments recently undertaken, we are able not only to add to the evidence upon this point by showing that the natural odor of Anabæna is due to a similar oily product, but also to draw a sharp distinction between the natural odors of the microscopical organisms found in surface waters and the odors produced by their decay.

The following is a list of the microscopical organisms which have up to the present time been known to give to surface waters a disagreeable odor and taste. The genera in italics are those which have been thus far the most prominent in this respect.

The list of natural odors given are all odors of growth, and are products of the life of the organisms and not of their decomposition. It is only in the case of the Cyanophyceæ (so far as we are aware) that we have a decided odor both of growth and of decay. Beggiatoa[1] and some species of Chara[2] give off odors resembling that of hydrogen sulphide, which may be considered odors of decomposition. It will be seen later that these odors of decay are due to the peculiar chemical composition of the organisms.

---

[1] Proc. Am. Soc. of Microscopists (1884), p. 90.
St. Thomas's Hospital Reports, Vol. xx (1890), p. 51.
St. Thomas's Hospital Reports, Vol. xiii (1883), p. 39.
Comptes Rendus, xcv (1882), p. 846.
Comptes Rendus, ii (1879), p. 1078.
The Lancet, January 7, 1893, p. 22.

[2] Jour. of the New England Water Works Association, June, 1896.

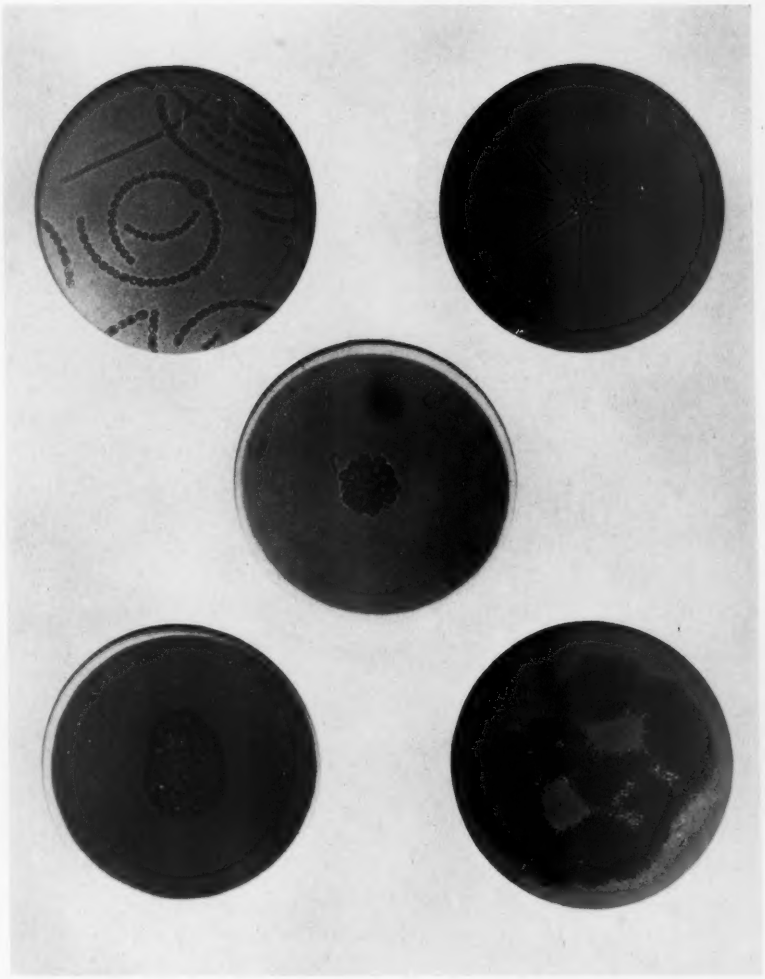
LIBRARY

Microörganisms.	Natural Odor.	Odor of Decay.
DIATOMACEÆ:		
Asterionella	Aromatic to fishy.	
Tabellaria	Aromatic.	
Meridion	Aromatic.	
CYANOPHYCEÆ. (Blue-green Algæ.)		
Anabæna	Mouldy, grassy.	Pig pen.
Rivularia	Mouldy, grassy.	Pig pen.
Clathrocystis	Sweet, grassy.	Pig pen.
Coelosphærium	Sweet, grassy.	Pig pen.
Aphanizomenon	Faintly grassy.	Pig pen.
CHLOROPHYCEÆ:		
Volvox	Fishy.	
Eudorina	Faintly fishy.	
Pandorina	Faintly fishy.	
INFUSORIA:		
Uroglena	Fishy and oily.	
Synura	Ripe cucumbers.	
Dinobryon	Fishy, like rockweed.	
Bursaria	Irish moss or salt marsh.	
Peridinium	Fishy, like clam shells.	
Cryptomonas	Candied violets.	
Mallomonas	Faintly fishy.	

Few surface waters are ever found to be entirely free from odor, but, as a rule, these odors are so faint as to be perceptible only when taken after shaking a considerable quantity of the water in a closed vessel. A description of the manner of taking odors and of the common terms employed to designate them, is given in a paper on "The Odor and Color of Surface Waters," by Dr. T. M. Drown.[1]

There is a decided difference in the strength of the natural odors produced by the various genera, and even by different species of the

[1] Jour. New England Water Works Association, March, 1888.



ANABÆNA. SYNURA. ASTERIONELLA.

UROGLENA. CLATHROCYSTIS.

The five microscopical organisms which most commonly produce disagreeable odors and tastes in drinking waters.

FROM A PHOTOMICROGRAPH KINDLY LOANED BY MR. G. C. WHIPPLE.

same genus. Asterionella produces much the strongest odor yet observed among the Diatomaceæ, giving the aromatic odor and taste of geranium, and often when in very large numbers a disagreeable fishy odor. This change in the character of the odor is due to concentration. In the majority of cases when Asterionella has caused a disagreeable taste and odor, the growth has occurred in an open distributing reservoir, the source of supply of which has been wholly or in part a ground water. The difficulty may be overcome by pumping directly into the system, or by covering the distributing reservoir to exclude the light. Tabellaria gives a much less pronounced odor. Meridion[1] has not been found in large numbers in Massachusetts, and none of the other diatoms have yet been known to produce a disagreeable odor in water, although many genera have often occurred in enormous numbers.

The odor of growth of Anabæna is stronger in water than that of any of the other Cyanophyceæ yet observed, and some species of Anabæna are much stronger than others.

Rarely has Rivularia been found in large quantities in Massachusetts, but when so occurring it is hardly less offensive than Anabæna. Among the Chlorophyceæ only the Volvocineæ are known to give a disagreeable odor of growth to drinking water, and Volvox[2] is the only genus which has yet caused much trouble.

Uroglena heads the list of disagreeable infusoria, with a taste and odor of fish oil. Synura is probably the next in strength, giving a taste and odor something like ripe cucumbers. The odor from Dinobryon is faintly fishy, or like rockweed. Peridinium also gives a slightly fishy odor resembling clam shells. Cryptomonas gives an odor of candied violets.

The number of organisms per cubic centimeter necessary to produce a noticeable odor differs greatly with the various genera, and often with different species of the same genus. The odor is, as a rule, more pronounced when the organism is in a mature stage of growth. It would be convenient for reference if an approximate figure could be set for each objectionable species, showing the point where it

---

[1] Sporadic Growth of Certain Diatoms. By J. D. Hyatt. Proc. of American Soc. of Microscopists, 1882.

[2] The data in regard to the odor of this organism are confined to observations made at Hemlock Lake, Rochester, N. Y. See Trans. Am. Soc. Civil Engineers, Vol. xxi, Dec., 1889, p. 483.

would begin to cause trouble in a water supply. This, however, in the present state of our knowledge, cannot be done. A paper on "The Relative Taste and Odor Imparted to Water by Some Algæ and Infusoria," by F. F. Forbes,[1] bears upon this point.

The odors of growth of the diatoms and of the infusoria have been fairly well established to be due to oily compounds, although the oil itself has been actually isolated from the organisms only in the case of Uroglena, as before mentioned. The odors produced by the Volvocineæ are so like those of the infusoria that there is little doubt that they also may be ascribed to oily products.

The nature of the grassy odor of growth of the Cyanophyceæ has never heretofore been experimented upon, to our knowledge, and, inasmuch as this class of organisms also gives an extremely disagreeable odor of decomposition, the cause for which was not well established, it was decided to make Anabæna, which is the most troublesome of the Cyanophyceæ, the object of special study.

Anabæna. Odor of Growth.

Odor-producing organisms have been concentrated by precipitating them with aluminum hydrate in a tall cylindrical galvanized iron tank of a capacity of about forty gallons.

We have also found that the various tastes and odors produced by the living organisms may be preserved for reference for a very considable period of time by putting the concentrated organisms into pure glycerine.

In the case of Anabæna a great many fruitless experiments were performed to obtain the odor-giving principle in a concentrated state. The water containing the organisms was filtered through absorbent cotton and filter paper, and many extractions and distillations were made without avail. During the fall of 1895 the growth in certain parts of Ludlow Reservoir, Springfield, was very luxurious, and in the sheltered coves where the water was shallow the growth was enormous, and was found to be a practically pure culture of *Anabæna circinalis*.[2] An excellent opportunity was therefore afforded to study this particular species.

---

[1] Jour. New England Water Works Association, Vol. iv, December, 1891.

[2] Tableau synoptique des Nostochacees filamenteuses. Mém. de la Soc. des Sc. nat. de Cherbourg (1889), Bd. xxvi, pp. 138–152.

The odor of the organisms when fresh resembles the odor of mouldy grass, and reasoning from analogy with the other organisms in water already mentioned, it was inferred that the odor might be due to the presence of oily products. Accordingly, large quantities of the fresh organisms were treated with various reagents which would be capable of dissolving any oil which might be present in the cells. After several weeks of extraction the various samples were examined. It was found that the spores remained unacted upon, while the contents of the cells were in every case extracted. The spores and the extracted cells settled to the bottom of the flasks. The solutions above the precipitates were of a light yellowish color in the acetone, alcohol, and ether extracts. With gasolene the gelatinous material floated upon the water present, which was colored a deep blue from the extraction of the cyanophyll.

The liquid above the precipitates in the several extracts was filtered off and evaporated upon watch glasses. The odors from these residues were in all instances, with the exception of the residue from the gasolene, entirely unlike the original odor of the Anabæna. In the case of all the residues, except that from the gasolene, a large amount of organic material had been extracted, and this material gave a very distinct odor of its own, which may have covered up or changed the odor of any oily product present.

The gasolene used had been especially prepared for the purpose by allowing it to stand over concentrated sulphuric acid for nearly a year. It was then neutralized and carefully washed. This gasolene, of itself, gave no odor whatever upon evaporation. It also had the advantage over the other solvents in extracting nothing but the essential oil, in evaporating very rapidly, and in not being miscible with water.

On examination, the extracted material from the gasolene was found to consist of minute oil globules of exactly the same appearance as the essential oils, and giving the natural odor of fresh Anabæna very strongly and distinctly. The odor disappeared in a few days and only a resinous material remained. A microscopical examination of the extracts, which had previously been placed in a closed air cell, showed in one or two cases the presence of minute needle-like crystals which projected from the oil globules in all directions. It is a well-known fact that the essential oils often form needle-like crystals upon oxidation in the air. This explains the difficulty in isolating the minute oily products found in many of the microscopical growths in

water. When concentrated by most methods they are oxidized or changed before the final product can be obtained. In most cases, when the odor due to an essential oil begins to diminish and finally to disappear, it has been found that an oxidation of the hydrocarbon has occurred, and the oil has become a resinous body which is quite inodorous.

Beilstein[1] says, regarding essential oils, that they are commonly terpenes or polymeric derivatives of them, and that only very rarely are they entirely without terpenes in their composition. These bodies are rapidly oxidized by moisture and air to resinous compounds.

In using ether, alcohol, or acetone, we have compounds all of which contain oxygen and all of which are more or less miscible with water. This makes the chance of oxidation much greater than in the case of gasolene, which contains no oxygen in its composition and is not miscible with water. It may well be that the odor had disappeared from the ether, alcohol, and acetone extracts because of the oxidation of the oil, whereas, in the case of the gasolene, the oxidation had not taken place at all, or at least, had not gone so far.

Upon examination of the gasolene extract of Anabæna, after standing eighteen months, the characteristic grassy odor was still readily recognizable upon evaporation of the gasolene. The odor soon disappeared, however, after the gasolene had evaporated, showing the probable rapid oxidation of the odor-giving oil.

It is not surprising that the extremely minute quantity of oily matter which is present in Anabæna, and which is sufficient to produce an odor, should be so difficult to isolate, when we consider the instability of compounds of this nature, and the opportunities for oxidation under the artificial conditions imposed.

The foregoing experiments, in connection with what has already been recorded in regard to the odors of growth of the Diatomaceæ and of the infusoria, point to the conclusion that the odors produced by the undecomposed microscopical[2] organisms in drinking water are all due to compounds of the nature of essential oils.

---

[1] Handb. d. organischen Chemie. 2 Aufl., 3, 303.

[2] Report Mass. State Board of Health, Part II, page 797.

Anabæna. Odor of Decay.

At Ludlow Reservoir, in the latter part of October, 1895, a considerable quantity of the Anabæna, which had been left upon the edges of the reservoir after the water had been drawn down, was in varying stages of decay. In a cove sheltered from the wind, the water in several places near the shore was covered with a greenish scum or slime. Portions of this scum were streaked with yellow and brown matter, while in various places the water appeared to be covered with a light blue coating of a gelatinous nature. Deposited upon the edge of the reservoir in the hollows of the ground were masses of a blue-green jelly which gave off a decidedly offensive odor. Large lumps of this jelly floated near the shore upon the surface of the water.

Several large bottles of the fresher material were collected and brought to the laboratory. Analysis of the green gelatinous Anabæna at a stage just before decay sets in shows it to contain, when dry, 9.66 per cent. of nitrogen. This very high percentage of nitrogen is undoubtedly one of the reasons for the production of an offensive odor during decomposition. The analysis is of a pure culture of *Anabæna circinalis*. Dr. T. M. Drown[1] made an analysis of the growth from Ludlow Reservoir in 1889, and obtained 7.42 per cent. of nitrogen, but at that time the growth was mixed with Clathrocystis and other organisms. Previous to that time Professor W. R. Nichols[2] analyzed the growth in Ludlow Reservoir and obtained 11.18 per cent. of nitrogen. This was also a mixed growth.

The material in the bottles immediately began to form a gas which forced the gelatinous matter up to the neck of the bottle in the form of froth. One of these bottles was sealed, and the gas evolved was collected in a flask inverted over mercury. The evolution of the gas ceased after four or five days, and during that time several complete analyses were made of the gas which was collected. This work was also duplicated with samples of Anabæna collected subsequently.

The gas given off from the decomposing Anabæna contained the merest trace of hydrogen sulphide, but gave a strong test for sulphate after being passed through bromine water. This shows that there were volatile sulphur compounds in the gas which were only partially

[1] The Chemical Examination of Waters, Mass. State Board of Health (1890), p. 549. Examination of Water Supplies.

[2] Ninth Annual Report Mass. State Board of Health (1878), p. 157.

decomposed, and yet were in a state to produce a highly offensive odor.

The following table gives the average results of the analyses of several samples of this gas taken at different times:

ANALYSIS OF GAS EVOLVED FROM THE BACTERIAL DECOMPOSITION OF ANABÆNA.

Marsh gas	.8%
Carbonic acid	1.5%
Oxygen	2.9%
Nitrogen	12.4%
Hydrogen	82.4%

The large percentage of hydrogen given off suggests a number of interesting questions. The gas which remained dissolved in the liquid contained in the bottle, and which was consequently not evolved, was practically all carbonic acid and represented a very high percentage of the total gas produced.

The decomposing organisms in the bottles brought to the laboratory passed through several stages of decay. After the evolution of gas ceased, the green jelly-like mass became brownish in color, and floated upon the surface of the water. The water was highly colored by the cyanophyll which had been dissolved out of the cells of the Anabæna. The color of this water was a deep blue by transmitted light, and a blood red by reflected light. After several weeks the blue color disappeared, and the brown gelatinous mass containing the living spores of the Anabæna settled to the bottom of the bottle. An analogous state of affairs doubtless exists in reservoirs infested with Anabæna. The spores are set free in a similar manner by the decomposition of the organisms, and settle to the bottom of the reservoir to be revived when the conditions are again favorable for their growth.

The extremely disagreeable odor of the decomposing organisms, together with the presence of a considerable amount of sulphur in the gas evolved, led us to suspect the presence of a large amount of sulphur in the organism itself. It is well known that the mercaptans, and other organic compounds containing sulphur, give off very offensive odors, and it was thought that some such compounds might be formed by the bacterial decomposition of Anabæna. While we did not isolate any specific compound, analyses of the gelatinous material resulting from the decomposition of Anabæna showed the presence of a

large amount of sulphur and a considerable amount of phosphorus. A sample of *Aphanizomenon flos-aquæ* from Lake Cochituate which was collected by G. C. Whipple, Biologist of the Boston Water Works, produced the "pig pen" odor upon decomposition, and also showed a high per cent. of sulphur upon analysis. Etard and Olivier[1] have shown that in case of Oscillaria this sulphur is obtained by the organism from the sulphates dissolved in the water.

The odor of decomposing Anabæna is evidently not due, to any extent, to the production of hydrogen sulphide, but to the partial breaking-down of highly organized compounds of sulphur and phosphorus. The odor is undoubtedly more offensive on account of the high per cent. of nitrogen present. It is true of the whole organic world that those products which give the most offensive odors of decay are partially decomposed, highly nitrogenous compounds, containing sulphur or phosphorus.

In conclusion, we wish to draw a marked distinction between the odors of growth and the odors of decay of the organisms occurring in surface waters.

The *usual* cause for the disagreeable odors and tastes occurring in potable water is found in the presence of large numbers of certain microscopical organisms which secrete compounds of the nature of essential oils.

These odors and tastes are caused by *living*, or undecomposed organisms; and although they are often very disagreeable, the compounds which produce them are as harmless as those which give odors and tastes to fresh vegetables or fish.

On the other hand, the "pig pen" odor of the Cynophyceæ (blue-green algæ) is produced by the decay of highly nitrogenous organic matter in which partially decomposed sulphur and phosphorus compounds play the leading part. The sanitary significance of these partially decomposed compounds in drinking water is yet to be determined, but analysis would indicate that their effect upon the general health would be unfavorable were it not for the fact that they occur in such minute quantities.

In the case of the odors of growth, the ready oxidation of the odor-giving principle to form a non-odorous compound is of practical significance. It is possible that by the selection of filtering materials which

[1] Comptes Rendus de l'Academie des Sciences, Paris. Vol. 95, 1882, 846–849.

would liberate and subsequently either oxidize or absorb the oily products, we might be able during the season when these growths are most abundant, to materially improve many of our public water supplies which are periodically infested with disagreeable organisms.

There is a wide field open for the investigation of the growth and decay of micro-organisms from a chemical standpoint. A better knowledge of the chemical composition of the organisms themselves, and of the organic and mineral contents of the waters which the various genera infest, would undoubtedly better enable an expert to judge whether this or that proposed water supply is likely to be favorable or unfavorable to the growth of any of the objectionable micro-organisms occurring in surface waters.

We wish to express our obligations to Professor W. T. Sedgwick, Mrs. E. H. Richards, and Professor A. H. Gill, for valuable suggestions in the preparation of this paper.

REVIEW

—OF—

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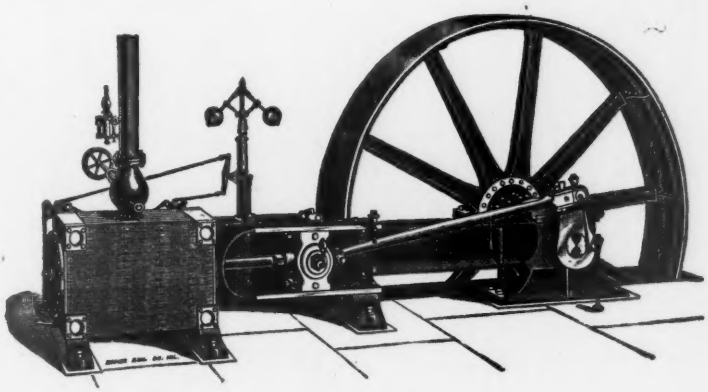

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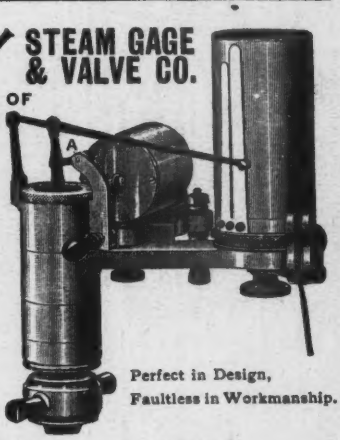

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